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Fate of Water Soluble Azo Dyes in the Activated Sludge Process

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16. ABSTRACT

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Mass balance calculations were made to determine the percentage of the dye compound in the waste activated sludge and in the activated sludge effluent. Of the 18 dyes studied, 11 compounds were found to pass through the activated sludge process substantially untreated, 4 were significantly adsorbed onto the waste activated sludge and 3 were apparently biodegraded.

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FATE OF WATER SOLUBLE AZO DYES IN THE ACTIVATED SLUDGE PROCESS

by

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxic Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report presents results from a research project designed to investigate the fate of 18 water soluble azo dyes in the activated sludge process. Azo dyes are of concern because they or their degradation products have been shown to be, or are suspected to be, carcinogenic. Since these 18 dyes are structurally similar to new dyes being submitted to EPA's premanufacturing notification review process, this work has initiated a data base that will aid in the prediction of the fate of new azo dyes.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

The objective of this study was to determine the partitioning of water soluble azo dyes in the activated sludge process. Azo dyes are of concern because some of the dyes, dye precurors, and/or their degradation products such as aromatic amines (which are also dye precurors), have been shown to be, or are suspected to be, carcinogenic. Specific azo dyes were spiked at 1 and 5 mg/L to pilot-scale treatment systems with both liquid and sludge samples collected. Samples were analyzed by high performance liquid chromatography with an ultraviolet-visible detector.

Mass balance calculations were made to determine the percentage of the dye compound in the waste activated sludge and in the activated sludge effluent. Of the 18 dyes studied, 11 compounds were found to pass through the activated sludge process substantially untreated, 4 were significantly adsorbed onto the waste activated sludge and 3 were apparently biodegraded.

This report covers a period from June 1985 to August 1987.

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LIST OF ABBREVIATIONS AND SYMBOLS

OTS	Office of Toxic Substances
PMN	Premanufacturing notification
-N=N-	Azo bond
ASP	Activated sludge process
SRT	Solids retention time
mg/L	Milligrams per liter
L/d	Liters per day
mg/d	Milligrams per day
mg/g	Milligrams per gram
^{o}C	Degrees centigrade
INF	Influent
PE	Primary effluent
ASE	Activated sludge effluent (secondary effluent)
ML	Mixed liquor
WAS	Waste activated sludge
MLSS	Mixed liquor suspended solids
SOL	Soluble fraction from WAS samples
RES	Residue fraction from WAS samples
HPLC	High performance liquid chromatography
TSS	Total suspended solids
C.I.	Colour Index (Reference #12)
x	Mean recovery
s	Standard deviation of recoveries
n	Number of determinations

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In addition, the authors wish to thank Dr. Eric Clarke and all representatives of the United States Operating Committee of the Ecological and Toxicological Association of the Dyestuffs Manufacturing Industries for supplying the dye compounds used in this study and participating in regular project review meetings.

SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency's (EPA) Office of Toxic Substances (OTS) evaluates Premanufacture Notification (PMN) submissions under section 5 of the Toxic Substances Control Act (TSCA). Azo dyes constitute a significant portion of these submissions. Generally, azo dyes contain between one and three azo linkages (-N=N-), linking phenyl and naphthyl radicals that are usually substituted with some combination of functional groups including: amino ($-NH_2$); chloro (-Cl); hydroxyl (-OH); methyl ($-CH_3$); nitro ($-NO_2$) and sulfonic acid, sodium salt ($-SO_3Na$). OTS is concerned because some of the dyes, dye precursors and/or their degradation products such as aromatic amines, which are also dye precursors, have been shown to be, or are suspected to be, carcinogenic (1).

One aspect of the PMN review process must estimate the release of a new chemical. The industrial manufacturing and processing of azo dyes will generate a wastewater contaminated with azo dyes, which is typically treated in a conventional wastewater treatment system. The effectiveness of this treatment must be known in order to estimate the release from this source. Therefore, EPA's Water Engineering Research Laboratory, Office of Research and Development undertook a study to determine the fate of specific water soluble azo dye compounds in the activated sludge process (ASP).

The study was approached by dosing the feed to pilot ASP systems with various water soluble azo dyes and monitoring each dye compound through the system, analyzing both liquid and sludge samples. The fate of the parent dye compound was assessed via mass balance calculations. From these data, it was possible to determine if the compound was removed by adsorption, apparent biodegradation or not removed at all. This report presents results for 18 dye compounds tested from June 1985 through August 1987. The study was conducted at EPA's Test and Evaluation Facility in Cincinnati, Ohio.

SECTION 2

CONCLUSIONS

1. A total of 18 water soluble azo dyes were successfully monitored in wastewater and sludge samples collected from pilot-scale activated sludge process treatment systems. The study of 11 additional dyes was attempted but could not be accomplished due to poor analytical recovery from wastewater and/or sludge samples.

2. Based on the compounds tested in this study, high water solubility, as judged by the degree of sulfonation, seemed to be a major factor in preventing an azo dye compound from being either apparently adsorbed or biodegraded by the activated sludge process.

3. The following 11 azo dyes were not substantially removed by the activated sludge process:

C.I. Acid Black 1	C.I. Acid Yellow 17
C.I. Acid Orange 10	C.I. Acid Yellow 23
C.I. Acid Red 1	C.I. Acid Yellow 49
C.I. Acid Red 14	C.I. Acid Yellow 151
C.I. Acid Red 18	C.I. Direct Yellow 4
C.I. Acid Red 337	

4. The following four azo dyes were removed via apparent adsorption onto the waste activated sludge but biodegradation was not suspected:

   C.I. Acid Blue 113
   C.I. Acid Red 151
   C.I. Direct Violet 9
   C.I. Direct Yellow 28

5. Biodegradation was suspected in the removal of the following three azo dyes:

   C.I. Acid Orange 7
   C.I. Acid Orange 8
   C.I. Acid Red 88

SECTION 3

RECOMMENDATIONS

1. Since several azo dyes passed through the activated sludge process relatively untreated, further investigations into how to remove these compounds, and others like them, may be necessary.

2. Investigations into the degradation products resulting from the aerobic biodegradation of azo dyes may be necessary in order to determine if the degradation products, such as aromatic amines, persist in the water.

3. For those compounds which strongly adsorb onto waste activated sludge, investigations into their fate in anaerobic environments (e.g., anaerobic digesters or landfills) would be of value.

4. Additional testing of structurally related compounds to those tested in this study may allow structure activity relationships to be developed.

SECTION 4

LITERATURE REVIEW

Limited work on aerobic biological treatment systems has been done regarding the fate of specific dye compounds in industrial or industrial/municipal wastewaters. Most of the research on aerobic systems has utilized synthetic wastewater which allows use of simplified analytical methodology but does not represent the variability inherent in actual wastewaters. However, much of what has been done is still useful in predicting the fate of specific compounds in these treatment systems.

Straley (2) in his review of the literature stated that, "...dyes are generally recalcitrant to biodegradation since one of the important factors in selecting a dye is its resistance to oxidation". Although aerobic biodegradation may not be likely, some researchers have shown azo dyes to be slowly biodegraded under aerobic conditions (3,4,5). However, the primary removal mechanism of dyes from wastewater treated by activated sludge seems to be adsorption onto biological sludge solids (6,7).

Tincher (8) studied the removal of acid and disperse dyes (although not all dyes were of the azo type) in a synthetic industrial wastewater simulating a carpet dyeing process wastewater. Generally, he found wide fluctuations in removal of these dyes and speculated that when removal did occur the removal mechanism was probably adsorption onto sludge rather than biodegradation. He concluded that carbon adsorption in conjunction with biological treatment appeared to be a particularly effective treatment system for the removal of dyes from wastewaters.

Wuhrmann, et al. (9) stated that permeation of dyes through the cell membrane is the primary rate limiting step in the microbial decolorization of azo dyes; therefore, sulfonic acid substitution (causing increased water solubility) seems to be an effective inhibitor of permeation.

SECTION 5

EXPERIMENTAL PROGRAM

This paper describes work that used screened raw wastewater from the Greater Cincinnati Mill Creek Sewage Treatment Plant as the influent to three pilot-scale activated sludge biological treatment systems (two experimental and one control) operated in parallel. Each system consisted of a primary clarifier (33 liters), complete-mix aeration basin (200 liters) and a secondary clarifier (32 liters). The systems were designed to operate at variable flow rates with all flows controlled by variable speed peristaltic pumps. Wasting of primary sludge was performed manually while mixed liquor wasting from the aeration basin for control of the solids retention time (SRT) was performed automatically.

Each water soluble dye was dosed as commercial product to the screened raw wastewater for the two experimental systems operated in parallel at targeted active ingredient doses of 1 and 5 mg/L of influent flow (henceforth referred to as the low and high spike systems, respectively). Since it was desirous to spike the dyes into actual wastewaters, it was important that realistic dosages be selected. Discussions with OTS and representatives from a trade association, the Ecological and Toxicological Association of the Dyestuffs Manufacturing Industry, resulted in selection of these dosages. The principal focus of this work was on the ASP and as such the primary sludge was not sampled. Table 1 presents a summary of the average operating conditions of the pilot plant systems.

TABLE 1. SUMMARY OF OPERATING CONDITIONS

Parameter	Value
Influent flow rate, L/d	720
Primary sludge flow rate, L/d	6
Primary effluent flow rate, L/d	714
Mixed liquor wastage flow rate, L/d	67
Secondary effluent flow rate, L/d	647
Solids retention time, days	2.7
Hydraulic retention time, days	0.28
Dissolved oxygen, mg/L	2.0-4.0
Target influent spike dosages, mg/L	
Low	1
High	5
Influent pH, pH units	7.0-8.0
Aeration basin temperature, ^{o}C	21-25

Before each data collection phase, analytical dye recovery studies were conducted using organic free water, influent wastewater and mixed liquor. These studies were run in duplicate and each recovery study was repeated at least once in order to ensure that the compound could be extracted from these samples. Purified dye standards were analytically prepared from the commercial dye product by repeated recrystallization.

The influent (INF), primary effluent (PE) and activated sludge effluent (ASE) samples were prepared as follows:

Step 1. One liter samples were filtered through 1.2 micron filter paper.

Step 2. Filtrate was passed through a glass column packed with resin. Filter paper and resin were then soaked for 16 hours in an ammonia-acetonitrile solution.

Step 3. Resin and filter paper were Soxhlet extracted with ammonia-acetonitrile for 16 hours.

Step 4. Extract was concentrated to 5 mL and brought up to 50 mL volume with methanol/dimethylformamide.

The mixed liquor (ML) samples were prepared as follows:

Step 1. One liter sample was filtered through 1.2 micron filter paper. The filtrate (SOL) was then prepared similar to the PE and ASE samples (Steps 2, 3 and 4) except the filter paper was not used in the extraction.

Step 2. The suspended residue (RES) and the filter paper were soaked for 16 hours in ammonia-acetonitrile solution then Soxhlet extracted with the ammonia-acetonitrile for 16 hours.

Step 3. Each extract was concentrated to 5 mL and brought up to 50 mL volume with methanol/dimethylformamide.

All extracted samples were analyzed by high performance liquid chromatography (HPLC) with an ultraviolet-visible detector.

All systems were operated for at least three times the SRT to ensure acclimation prior to initiation of data collection. During the data collection period the following analytical tests were performed:

- Total suspended solids (TSS) analyses on the INF, PE, ML and ASE samples. All samples were analyzed using EPA approved method 160.2-1 (10).

- Specific dye analyses on the INF, PE, ML and ASE samples. No standard method exists for these analyses, however a method developed by Tincher (8) and Dickson (11), and described above, was used.

All samples were 24-hour composites made up of six grab samples collected every four hours and stored at 4 ^{o}C. Each test run was sufficiently long to allow at least six sets of samples collected twice per week over three to five weeks (after acclimation) for the specific dye analyses. If acclimation appeared to be continuing during the data collection phase, the data collection period was extended accordingly.

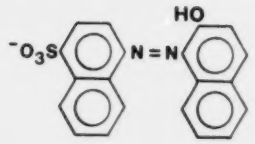
The 18 water soluble, acid and direct azo dyes that were studied in pilot-scale ASP systems are listed below in Table 2 by Colour Index (12) name and number with Figure 1 presenting the chemical structure for each.

TABLE 2. DYE COMPOUNDS SPIKED TO THE ACTIVATED SLUDGE PROCESS

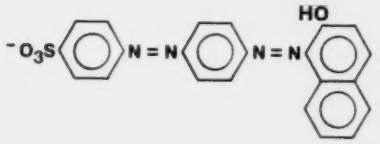
Colour Index Name	Colour Index Number
C.I. Acid Black 1	20470
C.I. Acid Blue 113	26360
C.I. Acid Orange 7	15510
C.I. Acid Orange 8	15575
C.I. Acid Orange 10	16230
C.I. Acid Red 1	18050
C.I. Acid Red 14	14720
C.I. Acid Red 18	16255
C.I. Acid Red 88	15620
C.I. Acid Red 151	26900
C.I. Acid Red 337	----- *
C.I. Acid Yellow 17	18965
C.I. Acid Yellow 23	19140
C.I. Acid Yellow 49	18640
C.I. Acid Yellow 151	13906
C.I. Direct Violet 9	27885
C.I. Direct Yellow 4	24890
C.I. Direct Yellow 28	19555

* Not assigned as of 12/87. Chemical Abstracts Number = 67786-14-5.

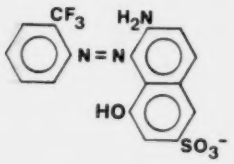
Table 3 presents the spike schedule for the above compounds. The start date was when the spike began to the experimental ASP systems. The time between the beginning of the acclimation period and the sampling period varied throughout the study but was always at least three times the SRT. Longer than expected acclimation periods were experienced for some dyes as slight modifications to the analytical methods were made in order to improve recovery.



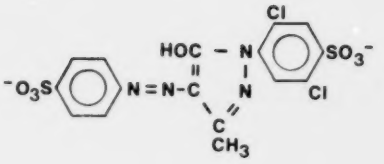
C.I. ACID RED 88



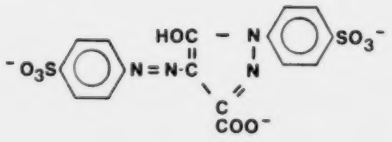
C.I. ACID RED 151



C.I. ACID RED 337



C.I. ACID YELLOW 17



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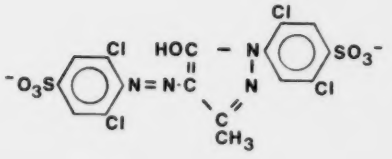

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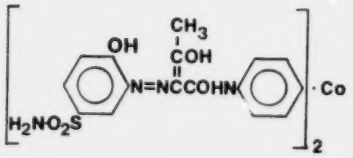

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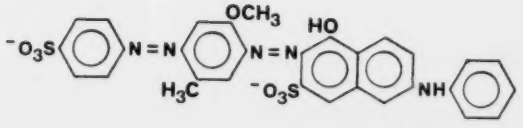
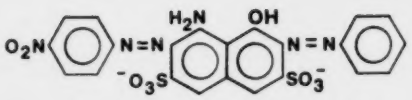
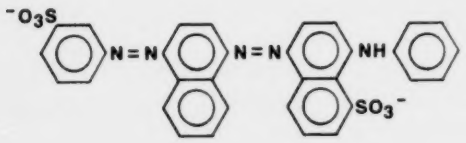


C.I. DIRECT VIOLET 9

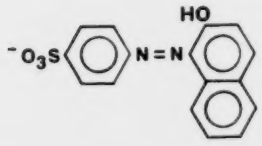
Figure 1. Chemical structures of test dyes. (continued)



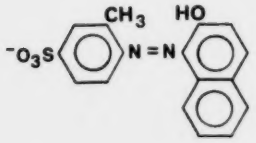
C.I. ACID BLACK 1



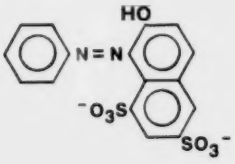
C.I. ACID BLUE 113



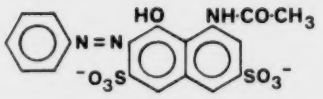
C.I. ACID ORANGE 7



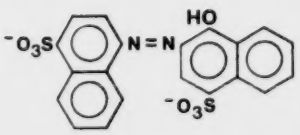
C.I. ACID ORANGE 8



C.I. ACID ORANGE 10



C.I. ACID RED 1



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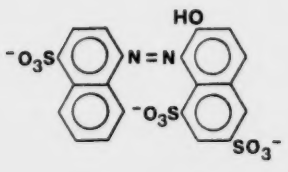
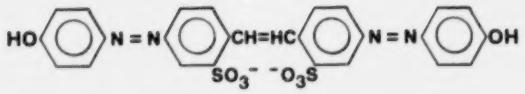
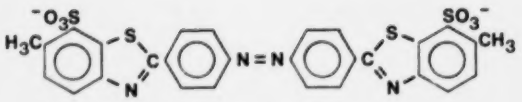


C.I. ACID RED 18

Figure 1. Chemical structures of test dyes. (continued)



C.I. DIRECT YELLOW 4



C.I. DIRECT YELLOW 28

Figure 1. Chemical structures of test dyes.

TABLE 3. SPIKE SCHEDULE

Colour Index Name	Start Date	Sampling Dates
C.I. Acid Red 88 C.I. Acid Red 151, Run 1	05-24-85	06-16-85 to 07-02-85
C.I. Acid Red 1 C.I. Acid Yellow 151	07-18-85	09-15-85 to 10-02-85
C.I. Acid Black 1, Run 1 C.I. Acid Orange 7, Run 1	10-11-85	11-03-85 to 11-20-85
C.I. Acid Orange 7, Run 2 *	10-11-85	01-05-86 to 02-09-86
C.I. Acid Blue 113 C.I. Acid Red 337	11-22-85	03-02-86 to 03-16-86
C.I. Acid Orange 10 C.I. Acid Red 14 **	02-25-86	04-16-86 to 05-04-86
C.I. Direct Violet 9, Run 1 C.I. Direct Red 81 ***	04-28-86	05-26-86 to 06-11-86
C.I. Acid Black 1, Run 2 C.I. Acid Orange 8	06-25-86	07-30-86 to 09-07-86
C.I. Acid Red 151, Run 2 C.I. Direct Violet 9, Run 2	08-20-86	11-12-86 to 12-03-86
C.I. Acid Yellow 17 C.I. Direct Yellow 28	01-09-87	03-29-87 to 04-22-87
C.I. Acid Red 18 C.I. Direct Yellow 4	04-28-87	05-27-87 to 06-22-87
C.I. Acid Red 14 C.I. Acid Yellow 23 C.I. Acid Yellow 49	06-26-87	07-19-87 to 08-30-87

* C.I. Acid Orange 7, Run 2 was intentionally spiked singularly. C.I. Acid Black 1 spiking was stopped on 12-10-85. The C.I. Acid Orange 7 spike continued uninterrupted.

** C.I. Acid Red 14 recoveries did not meet QA/QC requirements and spiking of this dye was stopped on 04-06-86. Note that C.I. Acid Red 14 recoveries were improved and subsequently spiked with C.I. Acid Yellow 23 and C.I. Acid Yellow 49.

*** C.I. Direct Red 81 recoveries did not meet QA/QC requirements and spiking of this this dye was stopped on 05-19-86.

SECTION 6

RESULTS AND DISCUSSION

Before a compound was judged acceptable for spiking into the pilot-scale treatment systems, spike recovery studies for each dye were conducted. These tests were conducted using laboratory, organic free water samples, and several wastewater and sludge samples from the control ASP. All samples were spiked and held at 4 ^{o}C for 24 hours before recovery was assessed. The possible removal mechanisms for a dye compound in the ASP system include adsorption, biodegradation, chemical transformation, photodegradation, and air stripping.

Table 4 presents the results from these determinations. Recovery for most dyes was within the targeted range of 80 to 120 percent; thus, it appeared that little or no chemical transformation occurred for these dyes due to contact with the variable wastewater and/or sludge matrix under these conditions. Some recoveries from wastewater and/or sludge samples for four dyes (C.I. Acid Black 1, C.I. Acid Blue 113, C.I. Acid Orange 10 and C.I. Acid Red 1) were outside the targeted range, but these dyes were accepted for sampling as it was felt that such recoveries were acceptable to the general project guidelines. As the recoveries for all 18 dyes were generally very good and with relatively low standard deviations, all values in the following data tables are presented as measured and no correction for recovery was made. In addition, photodegradation potential was investigated with each dye added to distilled/deionized water and no measurable decrease in concentration was observed for samples held in light for at least two weeks. Moreover, the estimated Henry's law constant for each dye tested was less than 10^{-15} atm-m^3/mol and as such, air stripping is very unlikely (13). Therefore, adsorption and/or biodegradation appeared to be the only removal mechanisms.

Table 5 presents the mean concentrations for each of the dyes tested. The raw data for each dye can be found in Appendix 1. Four dyes (C.I. Acid Black 1, C.I. Acid Orange 7, C.I. Acid Red 151 and C.I. Direct Violet 9) have two runs reported whereas all other dyes have just one. Additional runs were conducted for the above dyes for different reasons. C.I. Acid Red 151 and C.I. Direct Violet 9 were repeated in order to assess the reproducibility of the earlier results as the project guidelines required at least ten percent duplication of test runs. Upon inspection of the data for these dyes in Appendix 1, it can be seen that the values are not statistically different for each of the sampling locations. C.I. Acid Orange 7 was repeated to assess the reproducibility of the early results in order to determine if aerobic biodegradation was occurring as the data for C.I. Acid Orange 7, Run 1 suggested. Upon inspection of the raw data for each run, it can be seen that the values are not statistically different for each of the sampling locations. C.I. Acid Black 1 was repeated due to the generally poor recovery of the compound from the INF samples during Run 1. Similar results were achieved from Run 2. A discussion of all results is presented below.

From the results in Table 5 and the TSS data (see Appendix 1), mass balance calculations can be made. The guidesheet in Appendix 1 details how

TABLE 4. PERCENT RECOVERY OF TEST DYES FROM SAMPLE MATRICES

Dye Compound Name		Sample Matrix					
		Org. Free Water		Wastewater		Mixed Liquor	
		1 mg/L	5 mg/L	1 mg/L	5 mg/L	1 mg/L	5 mg/L
C.I. Acid Black 1, Run 1							
	x*	90	93	87	72	87	80
	s	3	2	1	13	11	2
	n	2	2	2	3	2	2
C.I. Acid Black 1, Run 2							
	x	69	78	79	90	77	83
	s	-	4	10	14	8	5
	n	1	2	4	4	4	4
C.I. Acid Blue 113							
	x	61	89	95	88	85	76
	s	32	10	4	2	12	10
	n	4	4	4	4	4	4
C.I. Acid Orange 7, Runs 1 and 2							
	x	101	97	97	97	98	90
	s	7	4	3	3	3	1
	n	2	2	4	3	2	2
C.I. Acid Orange 8							
	x	115	111	103	101	86	94
	s	-	1	5	4	13	11
	n	1	2	4	4	4	4
C.I. Acid Orange 10							
	x	**	**	91	80	74	73
	s	**	**	6	9	15	13
	n	**	**	7	6	8	8
C.I. Acid Red 1							
	x	**	**	105	95	65	92
	s	**	**	4	7	19	4
	n	**	**	2	2	2	2

(continued)

TABLE 4. (continued)

Dye Compound Name		Sample Matrix					
		Org. Free Water		Wastewater		Mixed Liquor	
		1 mg/L	5 mg/L	1 mg/L	5 mg/L	1 mg/L	5 mg/L
C.I. Acid Red 14							
	x	101	90	98	97	88	92
	s	2	14	1	4	14	7
	n	4	4	4	4	6	6
C.I. Acid Red 18							
	x	98	98	94	88	87	90
	s	5	5	14	13	19	4
	n	4	4	5	6	4	4
C.I. Acid Red 88							
	x	93	106	92	82	109	96
	s	1	5	21	7	15	0
	n	2	4	2	3	3	1
C.I. Acid Red 151							
	x	74	85	91	83	94	90
	s	18	5	2	5	3	6
	n	4	4	2	2	2	2
C.I. Acid Red 151, Run 2							
	x	**	**	103	83	101	84
	s	**	**	5	16	13	17
	n	**	**	8	8	8	7
C.I. Acid Red 337							
	x	89	88	95	88	95	85
	s	3	3	4	2	3	4
	n	4	4	4	4	4	4
C.I. Acid Yellow 17							
	x	101	98	92	97	99	97
	s	4	4	9	9	9	5
	n	4	4	4	4	6	6

(continued)

TABLE 4. (continued)

Dye Compound Name		Sample Matrix					
		Org. Free Water		Wastewater		Mixed Liquor	
		1 mg/L	5 mg/L	1 mg/L	5 mg/L	1 mg/L	5 mg/L
C.I. Acid Yellow 23							
	x	108	102	103	103	102	103
	s	5	2	6	3	6	4
	n	4	2	8	8	6	6
C.I. Acid Yellow 49							
	x	90	93	99	100	99	99
	s	-	2	1	2	4	2
	n	4	4	4	4	6	6
C.I. Acid Yellow 151							
	x	**	**	116	98	109	113
	s	**	**	3	14	2	3
	n	**	**	2	2	2	2
C.I. Direct Violet 9, Run 1							
	x	**	**	120	92	87	89
	s	**	**	15	7	11	12
	n	**	**	4	4	4	4
C.I. Direct Violet 9, Run 2							
	x	**	**	103	98	101	95
	s	**	**	3	4	10	6
	n	**	**	8	8	8	7
C.I. Direct Yellow 4							
	x	86	90	81	92	93	94
	s	5	4	2	5	8	5
	n	4	4	4	4	6	6
C.I. Direct Yellow 28							
	x	96	98	94	87	101	97
	s	4	2	6	5	6	5
	n	4	4	4	4	8	8

* x = mean recovery, s = standard deviation of recoveries, n = number of determinations

** not tested

TABLE 5. DYE CONCENTRATIONS DATA SUMMARY

Dye Compound Name	Low Spike+					High Spike+				
	INF	PE	ASE	SOL	RES*	INF	PE	ASE	SOL	RES*
Acid Black 1, Run 1	0.53	0.44	0.41	0.40	0.13	2.21	2.20	2.29	2.07	0.47
Acid Black 1, Run 2	0.43	<0.11	0.28	0.19	<0.04	2.59	<0.75	2.02	1.41	0.13
Acid Blue 113	1.00	0.84	0.07	0.04	3.98	5.27	4.55	0.84	0.44	19.86
Acid Orange 7, Run 1	0.99	0.95	0.19	<0.08	<0.03	4.96	5.34	0.24	0.15	<0.03
Acid Orange 7, Run 2	1.12	1.04	0.31	0.25	<0.03	6.18	5.53	0.77	0.58	<0.03
Acid Orange 8	0.80	0.82	<0.03	<0.02	<0.03	4.39	4.02	<0.10	<0.04	<0.03
Acid Orange 10	1.17	0.96	1.01	0.88	<0.03	5.44	5.55	5.49	4.94	<0.04
Acid Red 1	1.01	0.90	0.89	0.83	<0.01	4.71	4.43	4.48	4.43	0.05
Acid Red 14	0.90	0.66	0.77	0.74	<0.03	4.61	2.81	4.16	3.98	<0.11
Acid Red 18	1.21	1.23	1.33	1.12	<0.05	5.11	4.54	4.71	4.76	<0.04
Acid Red 88	**	0.68	0.04	0.02	0.11	**	3.96	<0.01	<0.01	0.07
Acid Red 151, Run 1	**	0.56	0.17	0.08	2.90	**	3.64	0.44	0.17	19.86
Acid Red 151, Run 2	0.96	0.71	0.24	0.09	2.61	4.81	4.31	0.54	0.36	18.85
Acid Red 337	1.20	1.13	0.93	0.68	1.15	5.46	5.06	4.40	3.61	4.08
Acid Yellow 17	0.97	0.95	0.92	0.93	<0.06	4.58	4.51	4.55	4.45	<0.05
Acid Yellow 23	1.33	1.23	1.32	1.30	<0.03	5.08	5.25	5.39	5.35	<0.03
Acid Yellow 49	1.14	1.14	0.84	0.86	0.14	5.17	5.42	3.59	3.79	0.44
Acid Yellow 151	1.29	0.61	0.49	0.26	0.46	6.44	4.05	4.08	2.66	4.31
Direct Violet 9, Run 1	0.95	0.78	0.41	0.21	2.93	5.30	4.71	0.99	0.38	23.38
Direct Violet 9, Run 2	0.98	0.83	0.61	0.32	1.74	5.22	4.72	1.32	0.59	23.44
Direct Yellow 4	0.84	0.76	0.76	0.58	0.08	3.90	3.31	3.17	2.97	0.21
Direct Yellow 28	0.93	0.87	0.18	0.11	5.18	3.74	3.69	0.63	0.25	22.83

\+ concentrations in mg/L
* mass in mg of dye adsorbed/gm of MLSS
** not sampled

these calculations were made and the results are summarized as Table 6. As discussed earlier, the underlying assumptions were that a dye compound may pass through the activated sludge process substantially untreated, or, if removal occurs, then the two dominant removal mechanisms would likely be adsorption and/or biodegradation.

TABLE 6. MASS BALANCE DATA SUMMARY

Dye Compound Name	Low Spike		High Spike	
	Percent Recovered	Percent Adsorbed	Percent Recovered	Percent Adsorbed
Acid Black 1, Run 1	96	3	105	2
Acid Black 1, Run 2	244	6	265	2
Acid Blue 113	74	66	65	47
Acid Orange 7, Run 1	19	<1	4	<1
Acid Orange 7, Run 2	30	<1	14	<1
Acid Orange 8	4	1	2	<1
Acid Orange 10	104	<1	98	<1
Acid Red 1	98	<1	101	<1
Acid Red 14	116	1	148	<1
Acid Red 18	107	<1	104	<1
Acid Red 88	7	<1	<1	<1
Acid Red 151, Run 1	73	44	78	66
Acid Red 151, Run 2	82	50	70	58
Acid Red 337	95	14	94	9
Acid Yellow 17	98	1	101	<1
Acid Yellow 23	107	<1	103	<1
Acid Yellow 49	75	1	68	1
Acid Yellow 151	89	13	114	17
Direct Violet 9, Run 1	93	43	89	69
Direct Violet 9, Run 2	100	29	92	66
Direct Yellow 4	99	1	96	1
Direct Yellow 28	78	59	75	59

If a compound in Table 6 was recovered near the targeted range of 80 to 120 percent, then it was assumed that this compound was not biodegraded since most of the compound was recovered. Conversely, if the recovery was less than 20 to 30 percent, then it was assumed the compound was apparently biodegraded. This assumption was valid only because preliminary recoveries (Table 4) indicated little or no problems recovering the compounds from the various sample matrices. Lastly, if the compound was recovered near the targeted range of 80 to 120 percent, then one must investigate the percent adsorbed data. If these data indicated less than 20 percent adsorbed, then it was assumed that the compound was substantially untreated by the ASP. However, if these data indicated that the percent adsorbed was greater than 30 percent, then it was concluded that such a compound was removed by apparent adsorption.

From Table 6 it can be seen that of the 18 azo dyes studied, eleven (approximately 60 percent) passed through the activated sludge process substantially untreated with the data from the low and high spike systems in excellent agreement for these dyes. These were:

C.I. Acid Black 1
C.I. Acid Orange 10
C.I. Acid Red 1
C.I. Acid Red 14
C.I. Acid Red 18
C.I. Acid Red 337
C.I. Acid Yellow 17
C.I. Acid Yellow 23
C.I. Acid Yellow 49
C.I. Acid Yellow 151
C.I. Direct Yellow 4

The relatively high sulfonic acid substitution of these dyes may explain why they were not removed. If the azo dye has high sulfonic acid substitution, then little or no adsorption of the dye by the microbial cell or cell by-products would occur, thus limiting the chance of aerobic biodegradation (9). Quantitative water solubility data were not available in the literature for any of the test dyes, thus precluding calculated comparisons. Therefore, water solubility generalizations must be made for the test dyes relative to each other. One generalization is that significant water solubility is caused by the sulfonic acid functional group. Ten of the 11 above dyes have at least two sulfonic acid functional groups (C.I. Acid Red 337 has one). For example, a dye chemist, desiring more water solubility, will increase the number of sulfonic acid functional groups on the phenyl and/or naphthyl radicals. Thus C.I. Acid Orange 10 is more water soluble than either C.I. Acid Orange 7 or C.I. Acid Orange 8 although all three compounds have the same skeleton chemical structure (see Figure 1).

The positioning of the sulfonic acid functional group(s) and the molecular weight of the compound also appears to have an affect on how the compound partitions. From Table 6, one notes that four compounds were found to be adsorbed onto the waste activated sludge and apparently not biodegraded. These were:

C.I. Acid Blue 113
C.I. Acid Red 151
C.I. Direct Violet 9
C.I. Direct Yellow 28

C.I. Acid Blue 113, C.I. Acid Red 151 and C.I. Direct Violet 9 represent three of the four disazo (two azo bonds) structures. Although these dyes are sulfonated compounds with two of the three having two sulfonic acid functional groups, they also have a greater molecular weight than the other compounds. Further investigations into the affect of sulfonation (both in number of groups and position) versus molecular weight are necessary before a relationship, if any exists, could be developed. The fourth disazo dye is C.I. Acid Black 1 which has been placed with the pass-through dyes. Yet upon inspection of the results in Table 5, one notes that approximately half of C.I. Acid Black 1 cannot be recovered from the influent (INF) samples. This apparent fixed loss occurred for both the low and high spike systems and happened during Runs 1 and 2. Recall from Table 4, that C.I. Acid Black 1 was one of the dyes that was slightly outside the targeted recovery range, but not as poor as was seen during the intensive sampling periods of Runs 1 or 2. This behavior cannot be explained.

From Table 6 it can be seen that three compounds appeared to be biodegraded. These were:

C.I. Acid Orange 7
C.I. Acid Orange 8
C.I. Acid Red 88

The conclusion that these compounds were apparently biodegraded comes from an inspection of the mass balance data. One notes for each compound, very little of the dye was recovered during sampling. However, the preliminary recovery studies showed that the compound could be recovered without difficulty from wastewater and sludge matrices (see Table 4). Since the compounds were not found in the ASE or ML samples, and chemical transformation appeared to not be occurring, then biodegradation would account for the loss of the parent compound.

From Table 6, it can be seen that two compounds (C.I. Acid Black 1 and C.I. Acid Red 14) had mass balance recovery values greater than expected. This was partially a result of how the mass balance recovery data were calculated. These two dyes exhibited a behavior that cannot be completely explained and a discussion of the C.I. Acid Black 1 data has been provided. From the raw data presented for C.I. Acid Red 14 in Appendix 1 and summarized in Table 5, it can be seen that the compound was recovered from the INF samples and the values were close to the targeted spiking levels of 1 and 5 mg/L for the low and high spike systems, respectively. However, very erratic recovery was achieved from the PE samples, suggesting that the compound was being partially transformed and no longer measured as the parent compound. Yet, when the ASE data were inspected it was noted that the dye had reappeared. One explanation for this is that the mild anaerobic conditions in the primary clarifier partially reduced the azo bond and then the oxidative conditions of the aeration basin brought the bond back. A similar behavior to that of C.I. Acid Red 14 was observed for C.I. Acid Black 1 in the comparison of INF to PE to ASE samples, although the previous discussion for C.I. Acid Black 1 suggested a possible fixed loss of the compound from the INF samples as well. When the mass balance calculations were made, the low PE values cause an apparent high recovery of these dyes (see Table 6).

The quality assurance/quality control guidelines for this project called for at least ten percent duplication of each sampling effort. A routine sampling effort involved the collection of nine samples (INF, PE, ASE and ML from the low and high spike systems each and an INF sample from the control system). Therefore, at least one sample was collected as a random field duplicate and the results are presented in Table 7. As can be seen from Table 7, the percent relative range of duplicates for all compounds was generally very good.

In addition to the 18 dyes thus far discussed, eleven other azo dyes were investigated during this study but the analytical recovery methodology did not produce satisfactory recoveries from the various matrices for these dyes. Table 8 identifies these dyes and Figure 2 presents the chemical structure for each.

TABLE 7. RELATIVE RANGE OF FIELD DUPLICATES*

	INF		PE		ASE		SOL		RES	
	%	mean	%	mean	%	mean	%	mean	%	mean
Acid Blue 113	13	(1.30)	39	(0.96)	38	(0.08)				
			2	(0.66)						
			7	(0.68)						
Acid Black 1	65	(1.78)			3	(2.98)	0	(0.48)	42	(0.12)
Run 1					4	(1.66)	26	(1.61)	6	(0.50)
							10	(2.06)	5	(0.42)
Acid Black 1			38	(0.34)	1	(1.42)	64	(0.14)	164	(0.56)
Run 2			143	(0.87)	9	(3.17)	4	(1.94)	63	(0.08)
			0	(<0.02)			21	(0.14)	0	(0.03)
							6	(1.44)	13	(0.08)
							9	(0.22)	80	(0.05)
							78	(1.51)	74	(0.27)
							8	(0.24)	44	(0.09)
Acid Orange 7	6	(5.97)			5	(0.20)	8	(0.50)	0	(0.08)
Run 1							40	(0.05)	0	(0.03)
Acid Orange 7	7	(5.90)	3	(1.00)	20	(0.54)	8	(1.12)	75	(0.04)
Run 2			35	(0.88)	13	(0.08)	42	(0.33)	100	(0.02)
			0	(1.59)	117	(0.06)				
					0	(0.04)				
Acid Orange 8			1	(0.68)	0	(<0.02)	0	(<0.02)	0	(<0.02)
			2	(3.84)			31	(0.16)	25	(0.04)
			5	(0.83)			0	(<0.02)	0	(<0.02)
							50	(0.03)	0	(<0.02)
							0	(<0.02)	0	(<0.02)
							0	(<0.02)	13	(0.16)
							0	(<0.02)	38	(0.08)
Acid Orange 10	24	(1.31)	1	(4.00)	10	(1.06)	8	(1.02)	0	(<0.02)
					9	(5.48)	14	(5.84)	50	(0.03)
Acid Red 1	13	(0.98)	1	(3.89)	1	(2.71)	44	(0.59)	0	(<0.01)
			6	(1.12)	4	(0.90)	6	(4.72)	13	(0.08)
Acid Red 14	5	(3.92)	1	(0.68)	0	(5.37)	6	(0.64)	117	(0.06)
			5	(0.88)	0	(0.78)	2	(4.52)	19	(0.16)
					1	(4.23)	2	(4.69)	42	(0.19)
							3	(0.77)	25	(0.04)
							4	(3.53)	19	(0.16)
							4	(0.82)	13	(0.08)
							1	(3.72)	0	(0.24)
							6	(0.73)	0	(0.04)

(continued)

TABLE 7. (continued)

	INF		PE		ASE		SOL		RES	
	%	mean	%	mean	%	mean	%	mean	%	mean
Acid Red 18	13	(0.98)	9	(1.18)	3	(5.00)	13	(1.58)	29	(0.07)
	8	(4.68)	6	(4.48)			20	(4.02)		LOST
							2	(5.35)	0	(<0.05)
Acid Red 88			4	(3.64)	18	(0.11)	0	(<0.01)	0	(0.06)
							0	(<0.01)	18	(0.11)
							0	(<0.01)	0	(0.04)
Acid Red 151 Run 1			4	(2.92)	28	(0.18)	17	(0.06)	10	(2.20)
							19	(0.16)	1	(21.18)
							0	(0.08)	8	(1.92)
							7	(0.14)	1	(18.00)
Acid Red 151 Run 2			11	(0.74)	36	(0.14)	24	(0.38)	17	(26.70)
					92	(0.39)	44	(0.09)	7	(4.14)
							10	(0.10)	35	(1.94)
Acid Red 337	26	(1.24)	2	(1.22)	6	(0.98)				
			21	(1.12)						
			6	(1.03)						
Acid Yellow 17	15	(1.10)	1	(0.84)	5	(4.93)	0	(0.57)	0	(<0.03)
	20	(3.82)	29	(3.63)			6	(4.89)	0	(<0.03)
			9	(0.98)			7	(0.96)	0	(<0.05)
							0	(4.59)	0	(<0.05)
							11	(0.96)	0	(<0.05)
							17	(4.30)	0	(<0.05)
Acid Yellow 23	2	(4.77)	3	(1.34)	3	(6.30)	7	(1.35)	0	(<0.02)
			1	(0.98)	0	(1.10)	1	(6.45)	0	(<0.02)
							8	(2.29)	0	(<0.02)
							1	(5.74)	0	(<0.02)
							5	(1.02)	0	(<0.02)
							2	(4.48)	0	(<0.02)
							3	(1.15)	0	(<0.02)
							2	(5.26)	22	(0.18)
							6	(1.07)	30	(0.10)
Acid Yellow 49	3	(4.86)	5	(1.02)	1	(5.45)	3	(0.69)	36	(0.14)
			6	(1.03)	3	(1.12)	3	(4.40)	4	(0.51)
					1	(4.74)	3	(4.84)	13	(0.54)
							2	(0.95)	31	(0.16)
							10	(0.72)	0	(4.82)
							2	(1.05)	12	(0.25)
							9	(2.24)	0	(0.72)
							10	(1.05)	14	(0.22)

(continued)

TABLE 7. (continued)

	INF		PE		ASE		SOL		RES	
	%	mean	%	mean	%	mean	%	mean	%	mean
Acid Yellow 151			28	(0.61)	27	(3.58)	9	(0.22)	34	(0.98)
			5	(4.40)	6	(0.36)	1	(2.98)	19	(7.88)
			2	(0.58)						
Direct Violet 9 Run 1					13	(0.47)	29	(0.25)	6	(3.63)
					14	(0.78)	4	(0.26)	27	(29.20)
Direct Violet 9 Run 2			22	(0.73)	11	(0.38)	50	(0.58)	19	(31.65)
					12	(1.31)	17	(0.30)	2	(2.68)
Direct Yellow 4	12	(0.68)	22	(0.64)	1	(3.64)	36	(0.50)	29	(0.07)
	8	(3.70)	3	(3.92)			38	(0.26)	4	(3.70)
							13	(0.47)	0	(<0.05)
Direct Yellow 28	13	(1.09)	29	(0.72)	0	(0.68)	88	(0.08)	16	(3.78)
	13	(3.73)	14	(2.78)			29	(0.07)	6	(5.55)
			10	(0.70)			4	(0.24)	7	(32.65)
							13	(0.08)	12	(5.80)
							11	(0.44)	7	(33.32)

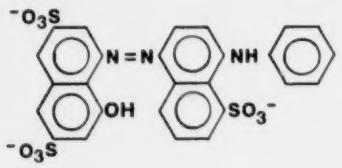
* Percent Relative Range of Duplicates = ((a - b) / x) 100

where a,b are duplicate pairs and x is the mean of a and b

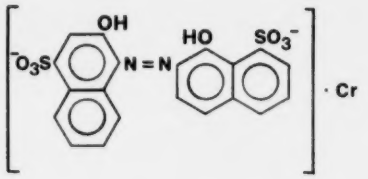
TABLE 8. DYE COMPOUNDS NOT TESTED DUE TO POOR RECOVERY

Colour Index Name	Colour Index Number
C.I. Acid Blue 92	13390
C.I. Acid Blue 158	14880
C.I. Acid Brown 14	14720
C.I. Acid Red 114	23635
C.I. Direct Black 80	31600
C.I. Direct Blue 15	24400
C.I. Direct Blue 78	34200
C.I. Direct Blue 80	24315
C.I. Direct Red 24	29185
C.I. Direct Red 80	35780
C.I. Direct Red 81	28160

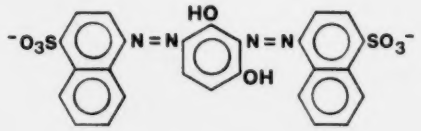
The recovery data for the above compounds are presented in Table 9. Generally these compounds were found to be unacceptable for intensive study as the compounds could not be recovered from the sludge samples and/or the resins used in the standard operating procedures. Although in some cases, recovery was good from organic free water samples, generally the recovery decreased in the wastewater and/or sludge samples. Two compounds, C.I. Acid Blue 92 and C.I. Direct Blue 15, had relatively good recovery when compared to those listed in Table 4. However, the standard deviations of the recoveries, resulted in a decision not to test the compounds.



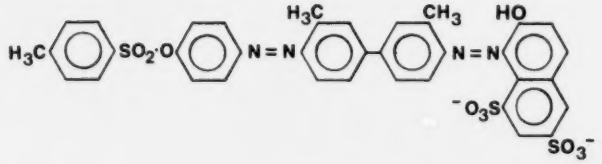
C.I. ACID BLUE 92



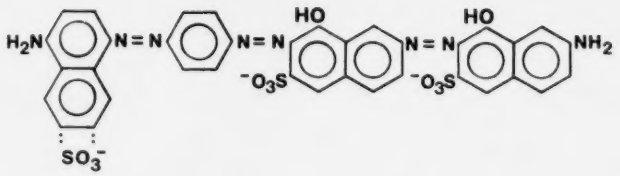
C.I. ACID BLUE 158



C.I. ACID BROWN 14

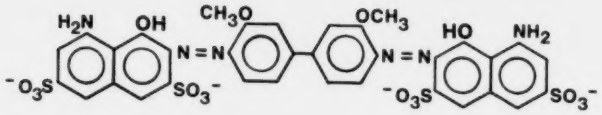


C.I. ACID RED 114

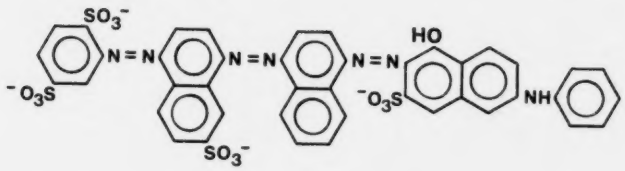


C.I. DIRECT BLACK 80

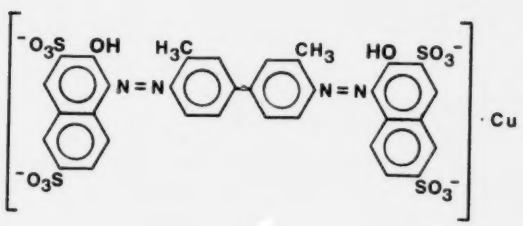
Figure 2. Chemical structures of failed dyes. (continued)



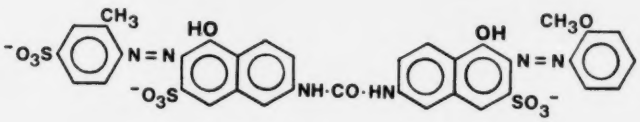
C.I. DIRECT BLUE 15



C.I. DIRECT BLUE 78



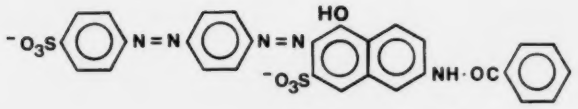
C.I. DIRECT BLUE 80



C.I. DIRECT RED 24

Figure 2. Chemical structures of failed dyes. (continued)

C.I. DIRECT RED 80



C.I. DIRECT RED 81

Figure 2. Chemical structures of failed dyes.

TABLE 9. PERCENT RECOVERY OF FAILED DYES FROM SAMPLE MATRICES

Dye Compound Name		Sample Matrix					
		Org. Free Water		Wastewater		Mixed LIquor	
		1 mg/L	5 mg/L	1 mg/L	5 mg/L	1 mg/L	5 mg/L
C.I. Acid Blue 92							
	x*	94	96	86	84	64	75
	s	3	5	4	3	31	19
	n	4	4	8	8	12	12
C.I. Acid Blue 158							
	x	28	44	11	22	7	20
	s	5	10	1	3	3	5
	n	4	4	3	2	4	4
C.I. Acid Brown 14							
	x	91	84	73	21	63	71
	s	4	9	7	3	15	16
	n	4	4	4	4	4	4
C.I. Acid Red 114							
	x	**	**	56	63	68	63
	s	**	**	4	3	3	5
	n	**	**	2	2	2	2
C.I. Direct Black 80							
	x	43	69	31	16	47	75
	s	18	2	8	5	28	1
	n	2	2	3	3	2	2
C.I. Direct Blue 15							
	x	95	98	82	75	87	82
	s	4	5	4	13	7	14
	n	4	4	10	9	8	8
C.I. Direct Blue 78							
	x	82	88	78	77	55	58
	s	22	13	12	15	33	27
	n	10	10	14	14	12	12

(continued)

TABLE 9. (continued)

Dye Compound Name		Sample Matrix: Org. Free Water 1 mg/L	Org. Free Water 5 mg/L	Wastewater 1 mg/L	Wastewater 5 mg/L	Mixed Liquor 1 mg/L	Mixed Liquor 5 mg/L
C.I. Direct Blue 80							
	x s n	COULD NOT BE DESORBED FROM RESIN					
C.I. Direct Red 24							
	x s n	COMPOUND WAS CHEMICALLY ALTERED DURING EXTRACTION					
C.I. Direct Red 80							
	x s n	COULD NOT BE DESORBED FROM RESIN					
C.I. Direct Red 81							
	x	**	**	95	72	14	35
	s	**	**	44	13	18	18
	n	**	**	4	4	4	4

* x = mean recovery, s = standard deviation of recoveries,

n = number of determinations

** not tested

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APPENDIX

ANALYTICAL DATA RESULTS

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GUIDE SHEET TO APPENDIX

Two pages have been devoted to each dye compound; the first page contains the dye concentration data and the second page contains the TSS data. Note that four dyes (C.I. Acid Black 1, C.I. Acid Orange 7, C.I. Acid Red 151 and C.I. Direct Violet 9) have two runs each. Each dye was spiked at two targeted concentrations, 1 and 5 mg/L, henceforth, referred to as the low spike and high spike, respectively. At each spike concentration, the activated sludge systems were sampled at the influent (INF), primary effluent (PE), activated sludge effluent (ASE) and waste activated sludge (WAS) sample ports. The WAS samples were separated into soluble (SOL) fractions and residue (RES) fractions.

The data presented in the following tables were collected after the systems had acclimated to the dye compound spike for a minimum of three times the solids retention time. In general between six to eight data sets were collected after the systems had achieved steady state. Some studies were extended past this goal as irregularities in the early data sets were observed, which may have indicated continued acclimation. However, all data were used to calculate the mean values when continued acclimation did not appear to have been occurring. Therefore, in some cases the number (n) of data sets equals 17.

As noted on each dye concentration data page, some samples were lost due to sampling errors, or more generally, laboratory accidents. However, the completeness exceeded 99 percent for all samples. Four dyes (C.I. Acid Red 1, C.I. Acid Red 88, C.I. Acid Red 151, Run 1 and C.I. Acid Yellow 151) were either rarely sampled or not sampled at the INF ports. These dyes were the first four dyes studied and at that time the analytical laboratory could process a limited number of samples. The INF samples were least important as all mass balance calculations were to be made on the activated sludge process and not on the primary clarifier. However, the analytical limitations were remedied and all subsequent dyes were sampled at the INF port.

The mass balance calculations around the activated sludge process were performed according to the following equations:

IN = mass of dye in the PE per day

= (PE flow rate, L/d) * (mean PE dye concentration, mg/L)

= (714 L/d) * (mean PE dye concentration, mg/L)

OUT = mass of dye in the ASE per day

= (ASE flow rate, L/d) * (mean ASE dye concentration, mg/L)

= (647 L/d) * (mean ASE dye concentration, mg/L)

WAS = mass of dye in WAS per day

= ((WAS flow rate, L/d) * (mean SOL dye concentration, mg/L)) +

((WAS flow rate, L/d) * (mean RES dye mass per mass of TSS, mg/g) *

(mean MLSS concentration, g/L))

= ((67 L/d) * (mean SOL dye concentration, mg/L)) +

((67 L/d) * (mean RES dye mass per mass of TSS, mg/g) *

(mean MLSS concentration, g/L))

The percent dye recovered was calculated as follows:

Percent Recovered = ((OUT + WAS)/IN) * (100)

The percent dye adsorbed was calculated as follows:

Percent Adsorbed = (((WAS flow rate, L/D) * (mean RES dye mass per mass of

TSS, mg/g) * (mean MLSS concentration, g/L)) / (IN)) * (100)

= (((67 L/d) * (mean RES dye mass per mass of TSS, mg/g) *

(mean MLSS concentration, g/L)) / (IN)) * (100)

C.I. Acid Black 1, Run 1

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
11-03-85	0.62	0.53	0.48	0.48	0.05	2.38	2.45	2.78	2.62	0.47
11-06-85	0.45	0.32	0.25	0.22	0.09	1.78	1.56	1.83	1.49	0.42
11-11-85	0.58	0.52	0.58	0.51	0.14	2.96	2.51	2.98	2.51	0.45
11-13-85	LOST	0.37	0.29	0.43	0.16	1.28	1.70	1.95	1.61	0.53
11-17-85	0.42	0.43	0.30	0.24	0.14	2.33	2.39	1.66	2.14	**
11-20-85	0.57	0.46	0.54	0.52	0.20	2.55	2.56	2.52	2.06	0.48
AVERAGE	0.53	0.44	0.41	0.40	0.13	2.21	2.20	2.29	2.07	0.47
ST.DEVN	0.08	0.08	0.13	0.12	0.05	0.54	0.40	0.50	0.42	0.03
NUMBER	5	6	6	6	6	6	6	6	6	5

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE		HIGH SPIKE	
MATERIAL BALANCE CALCULATIONS		MATERIAL BALANCE CALCULATIONS	
Flow Rate =	500 ml/min	Flow Rate =	500 ml/min
1. IN =	313 mg/day	1. IN =	1567 mg/day
2. OUT =	263 mg/day	2. OUT =	1479 mg/day
3. WAS =	37 mg/day	3. WAS =	167 mg/day
Percent Recovered =	96	Percent Recovered =	105
Percent Adsorbed =	3	Percent Adsorbed =	2

C.I. Acid Black 1, Run 1

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
11-03-85	140	150	7	2440	180	30	6	850
11-06-85	400	150	58	1380	390	110	100	860
11-11-85	250	170	8	870	210	120	1	860
11-13-85	190	120	6	860	190	80	4	970
11-17-85	130	120	12	860	140	140	11	1030
11-20-85	140	150	9	800	140	60	4	880
AVERAGE	208	143	17	1202	208	90	21	908
ST.DEVN	95	18	19	587	85	37	35	68
NUMBER	6	6	6	6	6	6	6	6

C.I. Acid Black 1, Run 2

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
07-30-86	0.33	<0.02	0.25	0.10	0.10	2.28	0.20	1.76	0.21	0.17
08-03-86	0.26	<0.02	0.20	0.14	<0.01	0.22	<0.02	1.42	1.11	0.09
08-06-86	0.40	<0.02	0.20	0.18	<0.01	2.68	<0.02	1.76	1.94	0.05
08-10-86	0.38	0.34	0.30	0.22	0.04	3.93	2.88	2.32	2.04	0.29
08-13-86	0.25	<0.02	0.34	0.03	0.02	2.41	<0.02	1.92	1.17	0.04
08-17-86	0.34	0.12	0.24	0.16	0.02	2.44	0.87	2.08	0.03	0.15
08-20-86	0.21	<0.02	0.27	0.22	<0.01	2.02	<0.02	1.00	1.44	0.05
08-24-86	0.90	0.17	0.30	0.22	0.04	2.63	1.12	1.97	1.45	0.02
08-27-86	0.55	0.31	0.40	0.32	0.10	3.55	1.33	3.17	2.82	0.18
09-01-86	0.52	0.28	0.23	0.16	0.07	3.16	2.13	2.65	1.51	0.17
09-03-86	0.56	<0.02	0.31	0.30	0.05	3.09	0.10	2.03	1.64	0.09
09-07-86	0.44	<0.02	0.30	0.24	0.06	2.70	0.25	2.11	1.60	0.21
AVERAGE	0.43	<0.11	0.28	0.19	<0.04	2.59	<0.75	2.02	1.41	0.13
ST.DEVN	0.18	0.12	0.06	0.08	0.03	0.89	0.91	0.53	0.72	0.08
NUMBER	12	12	12	12	12	12	12	12	12	12

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 81 mg/day	1. IN = 533 mg/day
2. OUT = 180 mg/day	2. OUT = 1304 mg/day
3. WAS = 17 mg/day	3. WAS = 107 mg/day
Percent Recovered = 244	Percent Recovered = 265
Percent Adsorbed = 6	Percent Adsorbed = 2

C.I. Acid Black 1, Run 2

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
07-30-86	290	170	5	1420	300	340	66	1440
08-03-86	280	180	5	1400	250	450	10	1370
08-06-86	330	210	13	1620	350	320	22	1630
08-10-86	390	160	2	1260	310	310	18	1020
08-13-86	430	280	8	1680	420	460	8	1670
08-17-86	220	160	8	1370	230	220	16	1440
08-20-86	630	90	11	1620	610	410	12	1540
08-24-86	380	230	7	1390	310	300	10	1400
08-27-86	340	170	5	1640	340	350	12	1520
09-01-86	340	170	12	1400	310	320	8	1560
09-03-86	470	250	8	1820	440	300	8	1820
09-07-86	380	230	7	1500	510	430	8	1650
AVERAGE	373	192	8	1510	365	351	17	1505
ST.DEVN	101	49	3	157	106	69	16	192
NUMBER	12	12	12	12	12	12	12	12

C.I. Acid Blue 113

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
03-02-86	1.30	1.14	0.11	0.05	5.84	5.86	**	0.78	0.57	27.98
03-05-86	1.16	0.96	0.05	0.06	3.00	**	4.33	0.76	0.39	16.32
03-09-86	0.94	0.78	0.08	0.05	**	5.07	4.23	0.98	0.51	**
03-12-86	0.88	0.66	LOST	<0.02	1.21	5.53	4.94	1.03	0.42	12.78
03-16-86	0.71	0.68	0.04	0.02	5.86	4.60	4.68	0.63	0.33	22.37
AVERAGE	1.00	0.84	0.07	0.04	3.98	5.27	4.55	0.84	0.44	19.86
ST.DEVN	0.21	0.18	0.03	0.02	1.98	0.48	0.28	0.15	0.09	5.81
NUMBER	5	5	4	5	4	4	4	5	5	4

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = OMITTED DUE TO KNOWN ERROR

LOW SPIKE		HIGH SPIKE	
MATERIAL BALANCE CALCULATIONS		MATERIAL BALANCE CALCULATIONS	
Flow Rate =	500 ml/min	Flow Rate =	500 ml/min
1. IN =	603 mg/day	1. IN =	3245 mg/day
2. OUT =	45 mg/day	2. OUT =	541 mg/day
3. WAS =	400 mg/day	3. WAS =	1560 mg/day
Percent Recovered =	74	Percent Recovered =	65
Percent Adsorbed =	66	Percent Adsorbed =	47

C.I. Acid Blue 113

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
03-02-86	160	190	4	1060	180	120	12	1090
03-05-86	310	260	11	1480	350	280	16	1440
03-09-86	230	140	6	1800	210	140	14	1200
03-12-86	380	240	6	1830	390	370	13	1260
03-16-86	160	120	10	1290	150	180	12	760
AVERAGE	248	190	7	1492	256	218	13	1150
ST.DEVN	86	54	3	296	96	94	1	226
NUMBER	5	5	5	5	5	5	5	5

C.I. Acid Orange 7, Run 1

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
11-03-85	1.04	1.04	0.51	0.05	0.04	4.30	5.43	0.50	0.39	0.06
11-06-85	0.95	0.97	0.34	0.28	0.03	5.96	5.77	0.38	0.28	0.03
11-11-85	0.97	0.94	0.06	<0.02	<0.02	5.80	5.59	0.20	0.07	<0.02
11-13-85	LOST	0.96	0.04	0.02	<0.02	5.56	5.24	0.18	0.05	0.02
11-17-85	0.96	0.96	0.08	0.04	<0.02	3.26	5.07	0.11	0.05	<0.02
11-20-85	1.05	0.85	0.08	0.05	0.03	4.89	4.92	0.05	0.03	<0.02
AVERAGE	0.99	0.95	0.19	<0.08	<0.03	4.96	5.34	0.24	0.15	<0.03
ST.DEVN	0.04	0.06	0.18	0.09	0.00	0.95	0.29	0.16	0.14	0.01
NUMBER	5	6	6	6	6	6	6	6	6	6

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 681 mg/day	1. IN = 3810 mg/day
2. OUT = 120 mg/day	2. OUT = 153 mg/day
3. WAS = 7 mg/day	3. WAS = 12 mg/day
Percent Recovered = 19	Percent Recovered = 4
Percent Adsorbed = <1	Percent Adsorbed = <1

C.I. Acid Orange 7, Run 1

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
11-03-85	140	150	7	2440	180	30	6	850
11-06-85	400	150	58	1380	390	110	100	860
11-11-85	250	170	8	870	210	120	1	860
11-13-85	190	120	6	860	190	80	4	970
11-17-85	130	120	12	860	140	140	11	1030
11-20-85	140	150	9	800	140	60	4	880
AVERAGE	208	143	17	1202	208	90	21	908
ST.DEVN	95	18	19	587	85	37	35	68
NUMBER	6	6	6	6	6	6	6	6

C.I. Acid Orange 7, Run 2

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
01-05-86	0.92	0.82	0.27	0.30	0.02	5.04	5.17	1.34	1.12	0.04
01-08-86	1.04	1.02	0.38	0.36	0.04	5.90	5.65	2.01	1.66	0.08
01-12-86	1.33	1.18	0.54	0.44	0.07	7.47	5.87	1.36	1.20	0.04
01-15-86	1.00	1.00	0.43	0.31	0.05	6.75	6.15	0.33	0.16	0.01
01-20-86	1.10	1.07	0.49	0.33	0.03	5.95	5.83	0.04	0.02	<0.01
01-22-86	1.10	0.88	0.54	0.43	0.05	5.61	5.42	0.05	0.03	<0.01
02-02-86	1.00	0.98	0.08	0.02	<0.01	5.37	4.93	1.11	0.80	<0.01
02-05-86	1.13	0.86	0.04	<0.01	<0.01	5.42	3.34	0.36	0.02	<0.01
02-09-86	1.49	1.59	0.04	0.01	<0.01	8.13	7.43	0.37	0.18	<0.01
AVERAGE	1.12	1.04	0.31	0.25	<0.03	6.18	5.53	0.77	0.58	<0.03
ST.DEVN	0.17	0.22	0.20	0.17	0.02	0.99	1.03	0.66	0.59	0.02
NUMBER	9	9	9	9	9	9	9	9	9	9

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 746 mg/day	1. IN = 3950 mg/day
2. OUT = 202 mg/day	2. OUT = 501 mg/day
3. WAS = 19 mg/day	3. WAS = 40 mg/day
Percent Recovered = 30	Percent Recovered = 14
Percent Adsorbed = <1	Percent Adsorbed = <1

C.I. Acid Orange 7, Run 2

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
01-05-86	210	140	102	620	200	130	34	920
01-08-86	290	190	12	970	290	200	110	890
01-12-86	180	130	10	900	190	140	120	840
01-15-86	300	240	6	1310	350	250	22	1400
01-20-86	190	120	17	790	200	130	8	880
01-22-86	260	190	38	1130	230	170	34	1160
02-02-86	230	190	9	1210	230	130	66	670
02-05-86	190	200	4	980	170	120	10	1060
02-09-86	110	80	1	810	100	60	1	690
AVERAGE	218	164	22	969	218	148	45	946
ST.DEVN	56	47	30	207	67	51	42	218
NUMBER	9	9	9	9	9	9	9	9

C.I. Acid Orange 8

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
07-30-86	0.64	0.67	0.03	<0.02	<0.02	2.80	3.20	0.65	<0.04	<0.02
08-03-86	0.62	0.64	0.02	<0.02	<0.02	3.18	2.67	<0.02	<0.02	<0.02
08-06-86	0.76	1.38	0.04	0.06	<0.02	3.74	5.09	0.07	0.16	<0.02
08-10-86	0.72	0.68	<0.02	<0.02	<0.02	5.74	5.70	0.04	<0.02	<0.02
08-13-86	0.68	0.63	0.03	<0.02	<0.02	3.84	3.02	0.15	0.06	<0.02
08-17-86	0.68	0.66	<0.02	<0.02	<0.02	4.02	3.84	0.02	<0.02	<0.02
08-20-86	0.80	0.73	0.03	<0.02	<0.02	4.36	2.52	0.03	<0.03	<0.02
08-24-86	0.88	0.81	<0.02	<0.02	<0.02	4.81	4.24	0.05	<0.02	<0.02
08-27-86	0.88	0.92	<0.02	<0.02	<0.02	5.27	4.22	<0.02	<0.02	<0.02
09-01-86	1.08	1.05	<0.02	<0.02	0.09	5.64	5.58	0.02	<0.02	0.10
09-03-86	0.99	0.83	<0.02	<0.02	0.09	4.85	4.36	0.04	<0.02	0.07
09-07-86	0.86	0.79	0.07	<0.02	0.05	4.46	3.85	0.09	<0.02	0.05
AVERAGE	0.80	0.82	<0.03	<0.02	<0.03	4.39	4.02	<0.10	<0.04	<0.03
ST.DEVN	0.14	0.21	0.01	0.01	0.03	0.89	1.02	0.17	0.04	0.03
NUMBER	12	12	12	12	12	12	12	12	12	12

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 583 mg/day	1. IN = 2873 mg/day
2. OUT = 18 mg/day	2. OUT = 65 mg/day
3. WAS = 5 mg/day	3. WAS = 6 mg/day
Percent Recovered = 4	Percent Recovered = 2
Percent Adsorbed = 1	Percent Adsorbed = <1

C.I. Acid Orange 8

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
07-30-86	290	170	5	1420	300	340	66	1440
08-03-86	280	180	5	1400	250	450	10	1370
08-06-86	330	210	13	1620	350	320	22	1630
08-10-86	390	160	2	1260	310	310	18	1020
08-13-86	430	280	8	1680	420	460	8	1670
08-17-86	220	160	8	1370	230	220	16	1440
08-20-86	630	90	11	1620	610	410	12	1540
08-24-86	380	230	7	1390	310	300	10	1400
08-27-86	340	170	5	1640	340	350	12	1520
09-01-86	340	170	12	1400	310	320	8	1560
09-03-86	470	250	8	1820	440	300	8	1820
09-07-86	380	230	7	1500	510	430	8	1650
AVERAGE	373	192	8	1510	365	351	17	1505
ST.DEVN	101	49	3	157	106	69	16	192
NUMBER	12	12	12	12	12	12	12	12

C.I. Acid Orange 10

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
04-16-86	1.24	0.59	0.57	0.84	<0.02	4.48	4.00	3.99	3.62	0.03
04-20-86	1.10	1.04	1.14	1.02	<0.02	5.99	5.05	6.07	5.55	<0.02
04-23-86	1.16	1.19	1.23	1.39	<0.02	5.98	5.85	5.54	5.84	<0.02
04-27-86	1.08	0.92	1.06	0.93	<0.02	5.34	5.78	5.27	4.51	0.06
04-30-86	1.12	1.15	0.93	0.30	0.07	5.79	5.86	5.48	5.34	0.08
05-04-86	1.31	0.86	1.11	0.81	<0.02	5.08	6.78	6.58	4.78	0.03
AVERAGE	1.17	0.96	1.01	0.88	<0.03	5.44	5.55	5.49	4.94	<0.04
ST.DEVN	0.08	0.20	0.22	0.32	0.02	0.54	0.86	0.80	0.74	0.02
NUMBER	6	6	6	6	6	6	6	6	6	6

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE		HIGH SPIKE	
MATERIAL BALANCE CALCULATIONS		MATERIAL BALANCE CALCULATIONS	
Flow Rate =	500 ml/min	Flow Rate =	500 ml/min
1. IN =	684 mg/day	1. IN =	3965 mg/day
2. OUT =	651 mg/day	2. OUT =	3551 mg/day
3. WAS =	61 mg/day	3. WAS =	334 mg/day
Percent Recovered =	104	Percent Recovered =	98
Percent Adsorbed =	<1	Percent Adsorbed =	<1

C.I. Acid Orange 10

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
04-16-86	280	160	4	1320	280	170	4	1160
04-20-86	220	120	10	920	200	120	9	920
04-23-86	280	240	7	1140	300	230	12	920
04-27-86	460	170	41	720	340	180	6	1210
04-30-86	350	220	LOST	1180	320	190	6	1280
05-04-86	320	170	12	1140	360	160	13	1380
AVERAGE	318	180	15	1070	300	175	8	1145
ST.DEVN	75	40	13	196	52	33	3	173
NUMBER	6	6	5	6	6	6	6	6

C.I. Acid Red 1

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
09-15-85	*	0.65	0.68	0.59	<0.01	*	4.51	3.99	4.53	<0.01
09-18-85	*	0.98	0.95	0.98	<0.01	*	5.30	5.55	5.18	0.04
09-22-85	*	1.12	1.02	1.13	<0.01	*	5.12	5.48	5.42	0.06
09-23-85	*	0.80	0.96	0.91	<0.01	*	4.30	4.93	4.72	0.05
09-24-85	*	0.75	0.94	0.60	<0.01	*	3.89	4.49	2.67	0.05
09-25-85	*	0.81	0.71	0.57	<0.01	*	2.94	2.71	3.19	0.04
09-29-85	1.01	1.12	0.92	0.91	0.02	4.54	4.71	4.31	4.59	0.06
10-02-85	1.00	0.97	0.90	0.93	<0.01	4.87	4.68	4.39	5.10	0.07
AVERAGE	1.01	0.90	0.89	0.83	<0.01	4.71	4.43	4.48	4.43	0.05
ST.DEVN	0.00	0.16	0.11	0.20		0.16	0.70	0.85	0.92	0.02
NUMBER	2	8	8	8	8	2	8	8	8	8

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 643 mg/day	1. IN = 3164 mg/day
2. OUT = 573 mg/day	2. OUT = 2899 mg/day
3. WAS = 57 mg/day	3. WAS = 302 mg/day
Percent Recovered = 98	Percent Recovered = 101
Percent Adsorbed = <1	Percent Adsorbed = <1

C.I. Acid Red 1

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
09-15-85	300	190	30	1960	300	280	21	1740
09-18-85	580	210	11	1970	580	300	3	1660
09-22-85	340	210	31	1560	340	370	12	1630
09-23-85	380	180	21	1630	380	240	7	1590
09-24-85	340	260	22	2160	340	270	LOST	1730
09-25-85	420	190	34	2290	420	250	18	1680
09-29-85	310	120	29	1790	310	170	13	1800
10-02-85	370	170	20	1560	370	230	14	1700
AVERAGE	380	191	25	1865	380	264	13	1691
ST.DEVN	84	37	7	259	84	54	6	62
NUMBER	8	8	8	8	8	8	7	8

C.I. Acid Red 14

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
07-19-87	0.87	0.68	0.71	0.71	<0.02	4.55	2.10	4.13	4.01	0.17
07-20-87	0.70	0.32	0.68	0.64	0.07	3.82	0.82	3.84	3.59	<0.03
07-27-87	0.98	0.83	0.89	0.71	0.05	4.76	4.34	4.52	4.52	0.13
07-29-87	1.03	0.82	0.68	0.64	0.04	4.61	1.64	4.16	3.51	<0.02
08-02-87	0.94	0.64	0.65	0.77	0.04	4.97	6.70	5.37	5.35	0.12
08-03-87	0.84	0.71	0.80	0.82	0.02	4.52	3.86	4.80	4.68	0.16
08-05-87	0.79	0.50	0.66	0.73	0.03	3.95	1.03	4.07	4.01	0.07
08-09-87	0.82	0.64	0.76	0.76	0.03	4.46	3.38	4.25	4.05	<0.02
08-10-87	0.96	0.62	0.78	0.74	<0.02	4.85	1.93	4.26	4.18	0.14
08-12-87	0.95	0.63	0.72	0.73	0.02	4.50	2.36	3.16	3.55	0.12
08-16-87	0.97	0.88	0.84	0.83	0.06	4.82	3.93	4.05	3.82	0.20
08-17-87	0.93	0.77	0.83	0.83	0.06	4.42	3.13	4.55	4.20	0.17
08-19-87	0.80	0.43	0.76	0.74	0.05	4.64	1.96	3.98	3.90	0.11
08-23-87	1.00	0.82	0.84	0.76	0.05	5.08	4.13	3.78	3.72	0.18
08-24-87	LOST	0.56	0.81	0.80	0.02	4.99	1.07	4.15	3.28	0.13
08-26-87	0.94	0.58	0.80	0.73	0.02	4.54	1.97	3.48	3.36	<0.02
08-30-87	0.86	0.86	0.84	0.68	<0.02	4.96	3.43	4.23	3.90	0.15
AVERAGE	0.90	0.66	0.77	0.74	<0.03	4.61	2.81	4.16	3.98	<0.11
ST.DEVN	0.09	0.15	0.07	0.06	0.02	0.33	1.47	0.48	0.50	0.06
NUMBER	16	17	17	17	17	17	17	17	17	17

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 474 mg/day	1. IN = 2007 mg/day
2. OUT = 497 mg/day	2. OUT = 2694 mg/day
3. WAS = 53 mg/day	3. WAS = 276 mg/day
Percent Recovered = 116	Percent Recovered = 148
Percent Adsorbed = 1	Percent Adsorbed = <1

C.I. Acid Red 14

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
07-19-87	150	50	15	910	60	70	7	1060
07-20-87	70	60	9	760	50	60	10	760
07-27-87	360	140	16	1080	290	180	14	1240
07-29-87	340	140	13	1380	310	250	9	1600
08-02-87	280	200	13	1370	330	90	9	1600
08-03-87	250	150	10	1260	240	90	4	1210
08-05-87	270	140	24	1420	290	190	4	1280
08-09-87	340	110	6	1180	330	140	5	950
08-10-87	340	170	6	1240	360	160	5	1000
08-12-87	310	210	17	1700	320	210	10	1350
08-16-87	290	130	8	1340	260	160	1	1340
08-17-87	360	130	10	1220	380	140	10	1220
08-19-87	280	170	5	1320	290	190	12	1470
08-23-87	300	130	5	1380	330	170	15	1330
08-24-87	440	200	8	1450	390	240	9	1340
08-26-87	470	200	9	1650	480	230	5	1860
08-30-87	310	190	7	1510	370	220	5	1630
AVERAGE	304	148	11	1304	299	164	8	1308
ST.DEVN	91	45	5	230	104	58	4	268
NUMBER	17	17	17	17	17	17	17	17

C.I. Acid Red 18

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
05-27-87	1.26	1.19	1.32	1.20	<0.02	5.21	4.56	4.74	4.75	0.11
05-31-87	0.97	1.76	1.59	1.64	0.07	4.73	5.18	5.29	5.34	<0.02
06-01-87	0.96	1.11	1.04	0.76	<0.02	4.49	4.30	4.19	4.29	<0.02
06-03-87	1.17	0.93	2.69	0.98	0.19	4.86	3.04	2.29	3.89	<0.02
06-07-87	0.62	0.71	0.73	0.81	<0.04	4.87	4.53	LOST	4.90	<0.03
06-08-87	1.77	1.69	1.43	1.47	<0.02	6.37	5.78	6.95	5.22	<0.03
06-15-87	2.23	1.92	1.46	1.45	<0.04	4.91	4.29	4.98	5.05	<0.05
06-17-87	1.46	1.46	1.27	1.18	<0.01	6.44	5.63	5.06	5.39	<0.04
06-21-87	0.89	0.83	0.84	0.92	0.06	4.68	3.87	4.58	4.55	<0.04
06-22-87	0.77	0.71	0.89	0.79	0.07	4.56	4.23	4.32	4.23	<0.05
AVERAGE	1.21	1.23	1.33	1.12	<0.05	5.11	4.54	4.71	4.76	<0.04
ST.DEVN	0.47	0.43	0.53	0.30	0.05	0.67	0.78	1.15	0.48	0.03
NUMBER	10	10	10	10	10	10	10	9	10	10

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 879 mg/day	1. IN = 3242 mg/day
2. OUT = 858 mg/day	2. OUT = 3048 mg/day
3. WAS = 79 mg/day	3. WAS = 323 mg/day
Percent Recovered = 107	Percent Recovered = 104
Percent Adsorbed = <1	Percent Adsorbed = <1

C.I. Acid Red 18

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
05-27-87	510	180	8	1660	470	190	23	1590
05-31-87	480	200	12	860	440	180	12	1190
06-01-87	420	190	34	900	360	190	15	1280
06-03-87	400	140	10	960	390	160	6	1420
06-07-87	380	130	2	1380	380	150	4	1660
06-08-87	340	150	6	1320	330	120	7	1890
06-15-87	400	170	12	1150	380	180	11	1000
06-17-87	440	180	15	1360	390	230	15	1300
06-21-87	390	170	8	870	470	150	8	1330
06-22-87	350	180	10	760	330	160	1	1110
AVERAGE	411	169	12	1122	394	171	10	1377
ST.DEVN	51	21	8	281	48	28	6	256
NUMBER	10	10	10	10	10	10	10	10

C.I. Acid Red 88

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
06-16-85	*	0.67	<0.01	<0.01	0.06	*	3.80	<0.01	<0.01	0.05
06-19-85	*	LOST	0.11	0.06	0.30	*	5.19	<0.01	<0.01	0.17
06-23-85	*	0.66	0.02	0.02	0.09	*	3.82	<0.01	<0.01	0.08
06-26-85	*	0.60	0.02	0.01	0.04	*	3.64	<0.01	<0.01	0.05
06-30-85	*	0.73	0.03	0.01	0.07	*	3.66	<0.01	<0.01	0.05
07-02-85	*	0.76	0.04	0.01	0.09	*	3.65	<0.01	<0.01	0.01
AVERAGE	*	0.68	0.04	0.02	0.11	*	3.96	<0.01	<0.01	0.07
ST.DEVN	*	0.06	0.03	0.02	0.09	*	0.55			0.05
NUMBER	*	5	6	6	6	*	6	6	6	6

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 488 mg/day	1. IN = 2827 mg/day
2. OUT = 25 mg/day	2. OUT = 6 mg/day
3. WAS = 8 mg/day	3. WAS = 6 mg/day
Percent Recovered = 7	Percent Recovered = <1
Percent Adsorbed = <1	Percent Adsorbed = <1

C.I. Acid Red 88

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
06-16-85	300	120	6	1040	300	160	12	1280
06-19-85	170	160	2	1350	170	170	7	1600
06-23-85	210	100	8	800	210	100	23	1110
06-26-85	460	240	31	1240	460	250	33	1510
06-30-85	250	100	14	560	250	50	2	980
07-02-85	330	140	22	460	330	190	54	1300
AVERAGE	287	143	14	908	287	153	22	1297
ST.DEVN	94	48	10	331	94	64	18	213
NUMBER	6	6	6	6	6	6	6	6

C.I. Acid Red 151, Run 1

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
06-16-85	*	0.52	0.10	0.06	2.12	*	3.81	0.35	0.13	23.83
06-19-85	*	LOST	0.17	0.08	2.29	*	5.04	0.44	0.21	19.25
06-23-85	*	0.52	0.14	0.08	2.91	*	3.28	0.30	0.16	19.10
06-26-85	*	0.42	0.22	0.09	1.53	*	2.92	0.46	0.19	15.17
06-30-85	*	0.59	0.20	0.08	3.48	*	3.16	0.59	0.19	27.96
07-02-85	*	0.77	0.21	0.11	5.04	*	3.62	0.48	0.14	13.85
AVERAGE	*	0.56	0.17	0.08	2.90	*	3.64	0.44	0.17	19.86
ST.DEVN	*	0.12	0.04	0.01	1.14	*	0.69	0.09	0.03	4.84
NUMBER	*	5	6	6	6	*	6	6	6	6

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 403 mg/day	1. IN = 2598 mg/day
2. OUT = 112 mg/day	2. OUT = 283 mg/day
3. WAS = 182 mg/day	3. WAS = 1737 mg/day
Percent Recovered = 73	Percent Recovered = 78
Percent Adsorbed = 44	Percent Adsorbed = 66

C.I. Acid Red 151, Run 1

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
06-16-85	300	120	6	1040	300	160	12	1280
06-19-85	170	160	2	1350	170	170	7	1600
06-23-85	210	100	8	800	210	100	23	1110
06-26-85	460	240	31	1240	460	250	33	1510
06-30-85	250	100	14	560	250	50	2	980
07-02-85	330	140	22	460	330	190	54	1300
AVERAGE	287	143	14	908	287	153	22	1297
ST.DEVN	94	48	10	331	94	64	18	213
NUMBER	6	6	6	6	6	6	6	6

C.I. Acid Red 151, Run 2

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
11-12-86	0.97	0.82	0.35	0.11	2.87	5.55	4.68	0.62	0.38	19.35
11-16-86	**	0.64	0.14	0.07	2.56	5.59	4.47	0.60	0.34	16.85
11-19-86	0.91	0.63	0.48	0.09	2.34	4.94	3.17	0.60	0.43	12.26
11-23-86	1.18	0.62	0.13	0.08	1.79	3.88	3.91	0.39	0.35	16.69
11-30-86	0.89	0.74	0.19	0.11	4.44	4.56	5.64	0.65	0.32	23.60
12-03-86	0.84	0.82	0.16	0.10	1.69	4.36	3.98	0.36	0.32	24.38
AVERAGE	0.96	0.71	0.24	0.09	2.61	4.81	4.31	0.54	0.36	18.85
ST.DEVN	0.12	0.09	0.13	0.01	0.92	0.62	0.76	0.12	0.04	4.19
NUMBER	5	6	6	6	6	6	6	6	6	6

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 508 mg/day	1. IN = 3076 mg/day
2. OUT = 156 mg/day	2. OUT = 347 mg/day
3. WAS = 261 mg/day	3. WAS = 1805 mg/day
Percent Recovered = 82	Percent Recovered = 70
Percent Adsorbed = 50	Percent Adsorbed = 58

C.I. Acid Red 151, Run 2

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
11-12-86	260	220	32	1660	230	190	32	1380
11-16-86	300	230	8	1800	290	210	10	1620
11-19-86	260	230	80	1770	330	190	4	1640
11-23-86	270	150	1	1680	230	170	4	1540
11-30-86	160	120	3	680	170	190	10	1000
12-03-86	160	130	4	1150	170	170	7	1280
AVERAGE	235	180	21	1457	237	187	11	1410
ST.DEVN	55	48	28	409	58	14	10	224
NUMBER	6	6	6	6	6	6	6	6

C.I. Acid Red 337

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
03-02-86	1.24	1.13	1.00	0.80	1.35	5.30	**	5.24	4.42	5.00
03-05-86	1.16	1.22	0.85	0.66	1.20	6.11	5.39	4.24	3.14	3.84
03-09-86	1.26	1.15	0.98	0.75	1.08	5.17	5.29	4.36	3.45	4.78
03-12-86	1.28	1.12	LOST	0.50	0.99	5.56	5.04	4.29	3.50	2.83
03-16-86	1.05	1.03	0.90	0.67	1.12	5.16	4.51	3.86	3.54	3.95
AVERAGE	1.20	1.13	0.93	0.68	1.15	5.46	5.06	4.40	3.61	4.08
ST.DEVN	0.08	0.06	0.06	0.10	0.12	0.36	0.34	0.46	0.43	0.77
NUMBER	5	5	4	5	5	5	4	5	5	5

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 807 mg/day	1. IN = 3611 mg/day
2. OUT = 603 mg/day	2. OUT = 2846 mg/day
3. WAS = 160 mg/day	3. WAS = 556 mg/day
Percent Recovered = 95	Percent Recovered = 94
Percent Adsorbed = 14	Percent Adsorbed = 9

C.I. Acid Red 337

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
03-02-86	160	190	4	1060	180	120	12	1090
03-05-86	310	260	11	1480	350	280	16	1440
03-09-86	230	140	6	1800	210	140	14	1200
03-12-86	380	240	6	1830	390	370	13	1260
03-16-86	160	120	10	1290	150	180	12	760
AVERAGE	248	190	7	1492	256	218	13	1150
ST.DEVN	86	54	3	296	96	94	1	226
NUMBER	5	5	5	5	5	5	5	5

C.I. Acid Yellow 17

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
03-29-87	0.64	0.84	0.82	1.01	0.07	4.46	4.60	4.30	4.38	0.05
03-30-87	0.59	0.62	0.57	0.57	<0.02	4.12	4.06	4.12	4.04	0.03
04-01-87	0.87	0.77	0.70	0.63	<0.05	4.30	3.63	3.94	3.94	<0.06
04-05-87	0.95	0.93	0.98	1.03	0.05	4.97	4.72	5.00	4.89	<0.03
04-06-87	1.10	1.10	1.03	1.07	<0.05	4.60	4.47	4.50	4.52	<0.05
04-08-87	1.00	0.98	0.97	0.96	<0.05	4.34	4.39	4.58	4.40	<0.06
04-12-87	0.94	0.84	0.93	0.95	<0.07	4.87	4.86	4.93	4.89	<0.06
04-13-87	0.89	0.96	0.79	0.73	<0.07	4.67	4.79	4.81	4.59	<0.06
04-15-87	0.90	0.94	0.91	0.86	0.06	4.64	4.38	4.70	4.75	<0.04
04-19-87	1.71	1.50	1.47	1.46	<0.06	3.82	4.24	4.25	4.02	<0.07
04-20-87	1.00	1.04	1.00	0.96	<0.07	5.16	5.45	4.79	4.62	<0.07
04-22-87	1.04	0.91	0.91	0.92	<0.04	5.05	4.54	4.63	4.30	<0.03
AVERAGE	0.97	0.95	0.92	0.93	<0.06	4.58	4.51	4.55	4.45	<0.05
ST.DEVN	0.27	0.20	0.21	0.22	0.01	0.38	0.43	0.32	0.31	0.01
NUMBER	12	12	12	12	12	12	12	12	12	12

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 680 mg/day	1. IN = 3221 mg/day
2. OUT = 597 mg/day	2. OUT = 2941 mg/day
3. WAS = 66 mg/day	3. WAS = 301 mg/day
Percent Recovered = 98	Percent Recovered = 101
Percent Adsorbed = 1	Percent Adsorbed = <1

C.I. Acid Yellow 17

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
03-29-87	390	140	10	1440	300	150	14	1340
03-30-87	190	90	8	1210	200	90	8	1180
04-01-87	260	110	14	1150	270	170	11	990
04-05-87	270	80	4	1010	240	90	3	970
04-06-87	170	90	2	1020	180	140	10	1000
04-08-87	210	120	2	1100	220	210	6	860
04-12-87	140	110	2	700	140	90	6	790
04-13-87	250	110	4	690	210	130	6	890
04-15-87	220	160	3	1470	230	190	8	1340
04-19-87	190	100	6	860	210	150	4	700
04-20-87	490	120	6	760	470	140	4	720
04-22-87	400	190	14	1180	450	280	11	1450
AVERAGE	265	118	6	1049	260	153	8	1019
ST.DEVN	102	30	4	251	98	53	3	243
NUMBER	12	12	12	12	12	12	12	12

C.I. Acid Yellow 23

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
07-19-87	1.33	1.34	1.37	1.47	<0.02	5.28	5.07	5.47	5.41	<0.02
07-20-87	1.56	1.33	1.36	1.35	<0.02	5.39	5.09	5.53	5.38	<0.02
07-27-87	2.50	2.18	2.45	2.26	<0.02	6.40	6.47	6.50	6.45	<0.02
07-29-87	2.60	2.39	2.22	2.29	<0.02	5.78	5.67	6.08	5.89	<0.02
08-02-87	1.28	1.27	1.34	1.29	<0.02	5.19	8.24	6.30	6.49	<0.02
08-03-87	1.19	1.16	1.17	1.19	0.06	5.21	5.09	5.80	5.74	<0.02
08-05-87	1.10	1.06	1.22	1.14	<0.02	4.77	4.52	5.21	5.10	<0.02
08-09-87	1.09	1.01	1.08	1.02	<0.02	4.94	5.07	5.04	4.86	<0.02
08-10-87	1.10	1.04	1.10	1.04	<0.02	5.07	5.27	5.42	5.22	<0.02
08-12-87	1.00	0.95	1.12	1.09	<0.02	4.49	4.37	4.12	4.48	<0.02
08-16-87	1.06	0.98	1.06	1.08	<0.02	4.62	4.72	5.14	5.08	<0.02
08-17-87	1.08	1.16	1.13	1.15	<0.02	4.56	4.78	4.93	5.29	<0.02
08-19-87	1.03	0.90	1.21	1.18	<0.02	4.94	4.90	5.13	5.05	<0.02
08-23-87	1.12	1.06	1.12	1.06	0.06	5.00	4.98	5.50	5.26	0.14
08-24-87	1.46	1.04	1.16	1.21	0.18	4.94	5.24	5.28	5.05	0.10
08-26-87	1.06	0.99	1.14	1.07	0.06	4.85	4.85	5.10	5.12	0.04
08-30-87	1.07	1.10	1.14	1.18	<0.02	5.00	4.86	5.09	5.04	0.01
AVERAGE	1.33	1.23	1.32	1.30	<0.03	5.08	5.25	5.39	5.35	<0.03
ST.DEVN	0.47	0.40	0.38	0.37	0.04	0.45	0.88	0.54	0.51	0.03
NUMBER	17	17	17	17	17	17	17	17	17	17

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 880 mg/day	1. IN = 3746 mg/day
2. OUT = 852 mg/day	2. OUT = 3488 mg/day
3. WAS = 90 mg/day	3. WAS = 361 mg/day
Percent Recovered = 107	Percent Recovered = 103
Percent Adsorbed = <1	Percent Adsorbed = <1

C.I. Acid Yellow 23

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
07-19-87	150	50	15	910	60	70	7	1060
07-20-87	70	60	9	760	50	60	10	760
07-27-87	360	140	16	1080	290	180	14	1240
07-29-87	340	140	13	1380	310	250	9	1600
08-02-87	280	200	13	1370	330	90	9	1600
08-03-87	250	150	10	1260	240	90	4	1210
08-05-87	270	140	24	1420	290	190	4	1280
08-09-87	340	110	6	1180	330	140	5	950
08-10-87	340	170	6	1240	360	160	5	1000
08-12-87	310	210	17	1700	320	210	10	1350
08-16-87	290	130	8	1340	260	160	1	1340
08-17-87	360	130	10	1220	380	140	10	1220
08-19-87	280	170	5	1320	290	190	12	1470
08-23-87	300	130	5	1380	330	170	15	1330
08-24-87	440	200	8	1450	390	240	9	1340
08-26-87	470	200	9	1650	480	230	5	1860
08-30-87	310	190	7	1510	370	220	5	1630
AVERAGE	304	148	11	1304	299	164	8	1308
ST.DEVN	91	45	5	230	104	58	4	268
NUMBER	17	17	17	17	17	17	17	17

C.I. Acid Yellow 49

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
07-19-87	0.97	1.02	0.81	0.83	0.13	4.90	5.23	4.23	3.98	0.43
07-20-87	0.99	0.98	0.75	0.69	0.18	5.07	5.11	3.62	3.14	0.62
07-27-87	1.02	1.00	1.00	0.84	0.14	5.10	5.24	4.32	4.40	0.41
07-29-87	1.09	1.00	0.55	0.39	0.08	5.04	4.94	2.91	3.17	<0.02
08-02-87	0.98	1.00	0.90	1.15	0.06	5.11	8.08	5.46	5.58	0.53
08-03-87	0.97	1.12	0.84	0.78	0.13	4.97	4.97	4.80	4.84	0.45
08-05-87	1.02	1.08	0.74	0.74	0.08	4.88	4.72	3.43	3.34	0.29
08-09-87	1.27	1.19	0.99	0.95	0.13	5.23	5.10	4.80	4.36	0.18
08-10-87	1.62	1.55	1.12	1.02	0.10	6.04	6.17	4.47	4.42	0.07
08-12-87	1.37	1.29	0.72	0.74	0.12	5.14	5.21	2.66	4.82	0.52
08-16-87	1.16	1.03	0.75	0.88	0.18	5.07	4.86	1.39	2.22	0.60
08-17-87	1.18	1.18	0.96	1.05	0.20	4.84	5.02	3.37	3.17	0.70
08-19-87	1.01	1.00	0.50	0.58	0.10	4.89	5.40	3.04	3.85	0.44
08-23-87	1.26	1.17	0.99	1.02	0.25	5.90	5.44	2.14	2.24	0.54
08-24-87	LOST	1.34	0.70	0.73	0.16	5.43	5.96	3.52	3.96	0.60
08-26-87	1.02	1.04	0.80	1.05	0.13	5.07	5.39	2.09	3.06	0.49
08-30-87	1.25	1.45	1.14	1.18	0.17	5.25	5.36	4.74	3.96	0.59
AVERAGE	1.14	1.14	0.84	0.86	0.14	5.17	5.42	3.59	3.79	0.44
ST.DEVN	0.18	0.17	0.17	0.20	0.05	0.33	0.75	1.09	0.89	0.19
NUMBER	16	17	17	17	17	17	17	17	17	17

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 816 mg/day	1. IN = 3872 mg/day
2. OUT = 543 mg/day	2. OUT = 2321 mg/day
3. WAS = 70 mg/day	3. WAS = 293 mg/day
Percent Recovered = 75	Percent Recovered = 68
Percent Adsorbed = 1	Percent Adsorbed = 1

C.I. Acid Yellow 49

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
07-19-87	150	50	15	910	60	70	7	1060
07-20-87	70	60	9	760	50	60	10	760
07-27-87	360	140	16	1080	290	180	14	1240
07-29-87	340	140	13	1380	310	250	9	1600
08-02-87	280	200	13	1370	330	90	9	1600
08-03-87	250	150	10	1260	240	90	4	1210
08-05-87	270	140	24	1420	290	190	4	1280
08-09-87	340	110	6	1180	330	140	5	950
08-10-87	340	170	6	1240	360	160	5	1000
08-12-87	310	210	17	1700	320	210	10	1350
08-16-87	290	130	8	1340	260	160	1	1340
08-17-87	360	130	10	1220	380	140	10	1220
08-19-87	280	170	5	1320	290	190	12	1470
08-23-87	300	130	5	1380	330	170	15	1330
08-24-87	440	200	8	1450	390	240	9	1340
08-26-87	470	200	9	1650	480	230	5	1860
08-30-87	310	190	7	1510	370	220	5	1630
AVERAGE	304	148	11	1304	299	164	8	1308
ST.DEVN	91	45	5	230	104	58	4	268
NUMBER	17	17	17	17	17	17	17	17

C.I. Acid Yellow 151

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
09-15-85	*	0.33	0.44	0.22	0.50	*	4.88	4.39	3.02	5.86
09-18-85	*	0.10	0.38	0.20	0.53	*	3.04	3.76	2.68	4.67
09-22-85	*	0.75	0.50	0.29	0.72	*	3.57	4.22	3.14	5.96
09-23-85	*	1.01	0.58	0.31	0.66	*	4.30	4.17	2.98	4.96
09-24-85	*	0.81	0.68	0.32	0.38	*	4.40	4.86	1.53	2.58
09-25-85	*	0.63	0.46	0.21	0.34	*	LOST	3.58	2.01	3.60
09-29-85	0.92	0.58	0.48	0.23	0.39	6.13	3.92	3.59	2.82	3.54
10-02-85	1.66	0.66	0.36	0.26	0.19	6.75	4.26	4.06	3.09	3.34
AVERAGE	1.29	0.61	0.49	0.26	0.46	6.44	4.05	4.08	2.66	4.31
ST.DEVN	0.37	0.27	0.10	0.04	0.16	0.31	0.56	0.41	0.54	1.16
NUMBER	2	8	8	8	8	2	7	8	8	8

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 435 mg/day	1. IN = 2894 mg/day
2. OUT = 314 mg/day	2. OUT = 2639 mg/day
3. WAS = 75 mg/day	3. WAS = 667 mg/day
Percent Recovered = 89	Percent Recovered = 114
Percent Adsorbed = 13	Percent Adsorbed = 17

C.I. Acid Yellow 151

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
09-15-85	300	190	30	1960	300	280	21	1740
09-18-85	580	210	11	1970	580	300	3	1660
09-22-85	340	210	31	1560	340	370	12	1630
09-23-85	380	180	21	1630	380	240	7	1590
09-24-85	340	260	22	2160	340	270	LOST	1730
09-25-85	420	190	34	2290	420	250	18	1680
09-29-85	310	120	29	1790	310	170	13	1800
10-02-85	370	170	20	1560	370	230	14	1700
AVERAGE	380	191	25	1865	380	264	13	1691
ST.DEVN	84	37	7	259	84	54	6	62
NUMBER	8	8	8	8	8	8	7	8

C.I. Direct Violet 9, Run 1

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
05-26-86	1.02	1.05	0.47	0.29	3.18	5.24	4.83	1.52	0.56	25.17
05-28-86	0.84	0.56	0.34	0.25	3.21	5.09	4.05	1.02	0.58	24.44
06-01-86	1.11	1.13	0.46	0.22	3.58	5.56	5.40	0.78	0.18	27.57
06-04-86	0.98	0.48	0.33	0.21	1.94	5.41	4.76	0.64	0.26	16.59
06-08-86	0.70	0.66	**	0.15	2.96	5.21	4.68	0.92	0.39	25.19
06-11-86	1.07	0.81	0.43	0.14	2.71	5.26	4.53	1.04	0.29	21.32
AVERAGE	0.95	0.78	0.41	0.21	2.93	5.30	4.71	0.99	0.38	23.38
ST.DEVN	0.14	0.24	0.06	0.05	0.52	0.15	0.40	0.28	0.15	3.55
NUMBER	6	6	5	6	6	6	6	6	6	6

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE		HIGH SPIKE	
MATERIAL BALANCE CALCULATIONS		MATERIAL BALANCE CALCULATIONS	
Flow Rate =	500 ml/min	Flow Rate =	500 ml/min
1. IN =	558 mg/day	1. IN =	3362 mg/day
2. OUT =	263 mg/day	2. OUT =	638 mg/day
3. WAS =	256 mg/day	3. WAS =	2341 mg/day
Percent Recovered =	93	Percent Recovered =	89
Percent Adsorbed =	43	Percent Adsorbed =	69

C.I. Direct Violet 9, Run 1

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
05-26-86	260	160	18	920	240	180	7	1200
05-28-86	330	240	9	1130	320	310	11	1260
06-01-86	380	230	19	1310	380	230	10	1440
06-04-86	400	230	4	1560	360	310	9	1760
06-08-86	210	170	15	1120	320	210	13	1540
06-11-86	310	280	29	1360	320	350	15	1670
AVERAGE	315	218	16	1233	323	265	11	1478
ST.DEVN	66	41	8	204	44	62	3	203
NUMBER	6	6	6	6	6	6	6	6

C.I. Direct Violet 9, Run 2

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
11-12-86	1.26	1.00	1.10	0.47	1.54	7.21	5.61	1.71	0.58	22.93
11-16-86	**	0.68	0.38	0.23	1.68	5.12	4.41	1.24	0.45	24.07
11-19-86	0.90	0.69	0.74	0.28	1.51	5.98	4.82	1.67	0.86	18.60
11-23-86	0.90	0.76	0.49	0.27	1.21	4.42	4.39	1.31	0.53	18.90
11-30-86	0.79	0.73	0.39	0.25	2.91	3.91	4.27	0.71	0.34	29.00
12-03-86	1.06	1.10	0.57	0.43	1.59	4.66	4.81	1.25	0.76	27.11
AVERAGE	0.98	0.83	0.61	0.32	1.74	5.22	4.72	1.32	0.59	23.44
ST.DEVN	0.16	0.16	0.25	0.09	0.54	1.10	0.45	0.33	0.18	3.85
NUMBER	5	6	6	6	6	6	6	6	6	6

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 590 mg/day	1. IN = 3369 mg/day
2. OUT = 396 mg/day	2. OUT = 851 mg/day
3. WAS = 192 mg/day	3. WAS = 2253 mg/day
Percent Recovered = 100	Percent Recovered = 92
Percent Adsorbed = 29	Percent Adsorbed = 66

C.I. Direct Violet 9, Run 2

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
11-12-86	260	220	32	1660	230	190	32	1380
11-16-86	300	230	8	1800	290	210	10	1620
11-19-86	260	230	80	1770	330	190	4	1640
11-23-86	270	150	1	1680	230	170	4	1540
11-30-86	160	120	3	680	170	190	10	1000
12-03-86	160	130	4	1150	170	170	7	1280
AVERAGE	235	180	21	1457	237	187	11	1410
ST.DEVN	55	48	28	409	58	14	10	224
NUMBER	6	6	6	6	6	6	6	6

C.I. Direct Yellow 4

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
05-27-87	0.85	0.66	0.74	0.62	0.13	4.76	3.86	3.37	3.21	0.39
05-31-87	0.91	1.07	0.64	0.57	0.06	3.42	3.16	3.08	2.92	0.45
06-01-87	0.70	0.64	0.68	0.64	<0.02	3.18	2.96	3.41	2.83	<0.02
06-03-87	0.72	0.70	1.88	0.64	<0.02	3.86	2.27	1.87	1.65	<0.02
06-07-87	0.54	0.45	0.52	0.48	0.17	3.95	3.92	LOST	3.23	0.72
06-08-87	0.72	0.45	0.33	0.50	0.05	3.78	3.14	3.52	3.52	<0.02
06-15-87	1.49	1.33	0.85	0.71	0.21	3.63	3.02	3.64	3.34	0.24
06-17-87	1.13	1.22	0.96	0.77	<0.04	5.45	4.47	4.06	3.70	0.20
06-21-87	0.74	0.56	0.48	0.44	0.06	3.70	3.24	2.96	2.74	0.07
06-22-87	0.63	0.56	0.54	0.47	0.07	3.31	3.02	2.64	2.54	0.05
AVERAGE	0.84	0.76	0.76	0.58	0.08	3.90	3.31	3.17	2.97	0.21
ST.DEVN	0.27	0.31	0.41	0.10	0.06	0.66	0.59	0.60	0.56	0.23
NUMBER	10	10	10	10	10	10	10	9	10	10

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE		HIGH SPIKE	
MATERIAL BALANCE CALCULATIONS		MATERIAL BALANCE CALCULATIONS	
Flow Rate =	500 ml/min	Flow Rate =	500 ml/min
1. IN =	545 mg/day	1. IN =	2360 mg/day
2. OUT =	493 mg/day	2. OUT =	2052 mg/day
3. WAS =	45 mg/day	3. WAS =	219 mg/day
Percent Recovered =	99	Percent Recovered =	96
Percent Adsorbed =	1	Percent Adsorbed =	1

C.I. Direct Yellow 4

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
05-27-87	510	180	8	1660	470	190	23	1590
05-31-87	480	200	12	860	440	180	12	1190
06-01-87	420	190	34	900	360	190	15	1280
06-03-87	400	140	10	960	390	160	6	1420
06-07-87	380	130	2	1380	380	150	4	1660
06-08-87	340	150	6	1320	330	120	7	1890
06-15-87	400	170	12	1150	380	180	11	1000
06-17-87	440	180	15	1360	390	230	15	1300
06-21-87	390	170	8	870	470	150	8	1330
06-22-87	350	180	10	760	330	160	1	1110
AVERAGE	411	169	12	1122	394	171	10	1377
ST.DEVN	51	21	8	281	48	28	6	256
NUMBER	10	10	10	10	10	10	10	10

C.I. Direct Yellow 28

DATE	LOW SPIKE					HIGH SPIKE				
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	SOL (mg/L)	RES (mg/g)
03-29-87	0.44	0.72	0.16	0.39	2.97	4.54	4.24	0.58	0.16	22.09
03-30-87	0.62	0.64	0.17	0.08	3.12	3.81	3.64	0.73	0.20	16.10
04-01-87	0.94	0.76	0.17	0.06	3.74	2.20	2.78	0.63	0.24	32.32
04-05-87	1.00	0.80	0.18	0.09	5.21	4.59	4.38	0.72	0.28	25.15
04-06-87	1.09	1.00	0.22	0.09	3.29	2.82	3.51	0.66	0.26	11.00
04-08-87	0.94	0.88	0.16	0.07	5.07	4.01	4.25	0.62	0.25	21.86
04-12-87	0.93	0.82	0.13	0.08	1.09	4.69	4.28	0.68	0.28	10.25
04-13-87	0.88	1.18	0.14	0.06	8.39	4.48	4.59	0.63	0.25	37.08
04-15-87	0.86	0.69	0.10	0.04	5.78	3.79	3.63	0.40	0.14	19.55
04-19-87	1.61	1.39	0.21	0.08	10.99	3.65	3.20	0.40	0.20	24.86
04-20-87	0.84	0.80	0.14	0.08	7.62	3.80	3.81	0.64	0.28	30.69
04-22-87	1.00	0.76	0.34	0.25	4.93	2.52	1.98	0.92	0.44	22.98
AVERAGE	0.93	0.87	0.18	0.11	5.18	3.74	3.69	0.63	0.25	22.83
ST.DEVN	0.27	0.21	0.06	0.10	2.61	0.80	0.72	0.13	0.07	7.75
NUMBER	12	12	12	12	12	12	12	12	12	12

LOST = LAB ACCIDENT; * = NOT SAMPLED; ** = DATA OMITTED DUE TO KNOWN ERROR

LOW SPIKE	HIGH SPIKE
MATERIAL BALANCE CALCULATIONS	MATERIAL BALANCE CALCULATIONS
Flow Rate = 500 ml/min	Flow Rate = 500 ml/min
1. IN = 621 mg/day	1. IN = 2635 mg/day
2. OUT = 114 mg/day	2. OUT = 410 mg/day
3. WAS = 372 mg/day	3. WAS = 1575 mg/day
Percent Recovered = 78	Percent Recovered = 75
Percent Adsorbed = 59	Percent Adsorbed = 59

C.I. Direct Yellow 28

DATE	LOW SPIKE - TSS DATA				HIGH SPIKE - TSS DATA			
(M-D-Y)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)	INF (mg/L)	PE (mg/L)	ASE (mg/L)	ML (mg/L)
03-29-87	390	140	10	1440	300	150	14	1340
03-30-87	190	90	8	1210	200	90	8	1180
04-01-87	260	110	14	1150	270	170	11	990
04-05-87	270	80	4	1010	240	90	3	970
04-06-87	170	90	2	1020	180	140	10	1000
04-08-87	210	120	2	1100	220	210	6	860
04-12-87	140	110	2	700	140	90	6	790
04-13-87	250	110	4	690	210	130	6	890
04-15-87	220	160	3	1470	230	190	8	1340
04-19-87	190	100	6	860	210	150	4	700
04-20-87	490	120	6	760	470	140	4	720
04-22-87	400	190	14	1180	450	280	11	1450
AVERAGE	265	118	6	1049	260	153	8	1019
ST.DEVN	102	30	4	251	98	53	3	243
NUMBER	12	12	12	12	12	12	12	12